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POPULATION DOSE FROM X-RAYS, UNITED STATES 1964. ESTIMATES OF GONAD AND GENETICALLY SIGNIFICANT DOSE FROM THE PUBLIC HEALTH SERVICE X-RAY EXPOSURE STUDY

Bureau of Radiological Health
Rockville, Maryland

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POPULATION DOSE FROM X-RAYS U.S. 1964

ESTIMATES OF GONAD AND GENETICALLY SIGNIFICANT DOSE FROM THE PUBLIC HEALTH SERVICE X-RAY EXPOSURE STUDY

Prepared by the Population
Exposure Studies Section,
Bureau of Radiological Health

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
Environmental Control Administration

FOREWORD

This report is based on one of a series of studies conducted by the United States Public Health Service to estimate population exposure from X-rays. Interest in this problem was manifested as early as 1952, and intensified in 1956, when studies were published in several countries suggesting that the levels of man-made genetically significant radiation were rather substantial. The early data on X-rays were a by-product of studies to determine the magnitude of radiation dose resulting from the nuclear weapons testing programs. These developments were a major factor in the establishment by the Public Health Service in 1958 of a Division of Radiological Health, which in 1968 became the Bureau of Radiological Health. Within the Public Health Service, the Bureau has primary responsibility for the support of beneficial uses of radiation while protecting the public against real and potential hazards.

The recent passage of the Radiation Health and Safety Act of 1968 (Public Law 90-602) reflects the growing concern of responsible persons and agencies for the need for research on the effects of radiation exposure to persons and the control of radiation hazards. The X-ray Exposure Study of 1964, in providing data on the exposure and dose resulting from medical diagnostic X-ray procedures, provides an essential baseline for evaluating the effectiveness of program efforts in the control of excess radiation exposure from these procedures.

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SYMBOLS

Not applicable	---
Quantity zero	0
Quantity less than 0.5 (except 0.05 for tables of Genetically Significant Dose)	-
Figure does not meet standards of reliability or precision	(*)

In all tables, totals have been independently generated and may, therefore, differ slightly from sums of their parts.

Chapter 1

OBJECTIVES AND OVERALL STUDY DESIGN

Chapter 1

OBJECTIVES AND OVERALL STUDY DESIGN

The importance of X-rays as a source of population exposure to radiation has been emphasized in numerous reports and articles (*1-8*). These indicate that an important segment of the total population exposure to radiation may be accounted for by medical and dental roentgenology. The need to obtain national data on the use of medical and dental X-rays and to develop programs to promote the efficient use of X-rays for diagnostic and therapeutic purposes has also been documented in professional publications and congressional testimony (*2-4, 9-11*).

The interest in obtaining basic information on the use of medical and dental X-rays is reflected by an increasing number of studies aimed at providing reliable estimates of the magnitude and distribution of population exposure to X-radiation. These studies include research on doses to specific body areas associated with exposures from selected X-ray examinations and procedures (*12-19*).

In 1961, the Division of Radiological Health (now the Bureau of Radiological Health) in cooperation with the National Center for Health Statistics (NCHS) collected information on the medical and dental X-ray experience of a representative sample of the civilian noninstitutional population residing in the United States (*20*). This initial study demonstrated the feasibility of collecting X-ray visit data by household interview, and provided the first nationwide estimates of X-ray visit data for the U.S. population.

In 1964, the Bureau of Radiological Health (BRH) and the NCHS conducted a study to estimate X-ray exposure and dose for the general population based upon the X-ray experience of a representative sample of the U.S. population (*21*). The principal objective of this study was to provide estimates of population exposure by type of examination or procedure for a variety of demographic and X-ray facility characteristics. The resultant data were intended to:

1. guide the development of programs aimed at assisting professional groups, health agencies, and equipment manufacturers in promoting more efficient use of x-rays in medical and dental practice;

2. develop hypotheses for further research, and to identify population groups and types of practices on which such research may be conducted;

3. establish baseline estimates of the magnitude and distribution of population exposure against which to evaluate the effectiveness of program efforts; and

4. provide a basis for estimating specific organ doses when used with appropriate dosimetric models.

The first report on the Public Health Service X-ray Exposure Study gives a complete description of the methods used to derive estimates of the magnitude and distribution of the X-ray experience of the U.S. population *(21)*. Estimates are presented of persons, visits, examinations, and films according to demographic and socioeconomic characteristics of the population and by types of facilities and specialities of the practitioners. Estimates of exposure at the skin associated with selected types of examinations are also included. The dose models developed for the study and estimates of gonad and genetic dose for the U.S. population are presented in this report.

STUDY DESIGN

The X-ray Exposure Study was conducted in several sequential stages (fig. 1):

1. a household interview survey of a representative sample of the U.S. population to obtain X-ray visit data;

2. a mail followup to the X-ray facilities where reported visits took place to obtain technical data;

3. the merging and processing of the above sets of data to produce estimates of the X-ray experience of the U.S. population;

4. the development of dosimetric models for estimating gonad dose from the exposure data generated by the X-ray

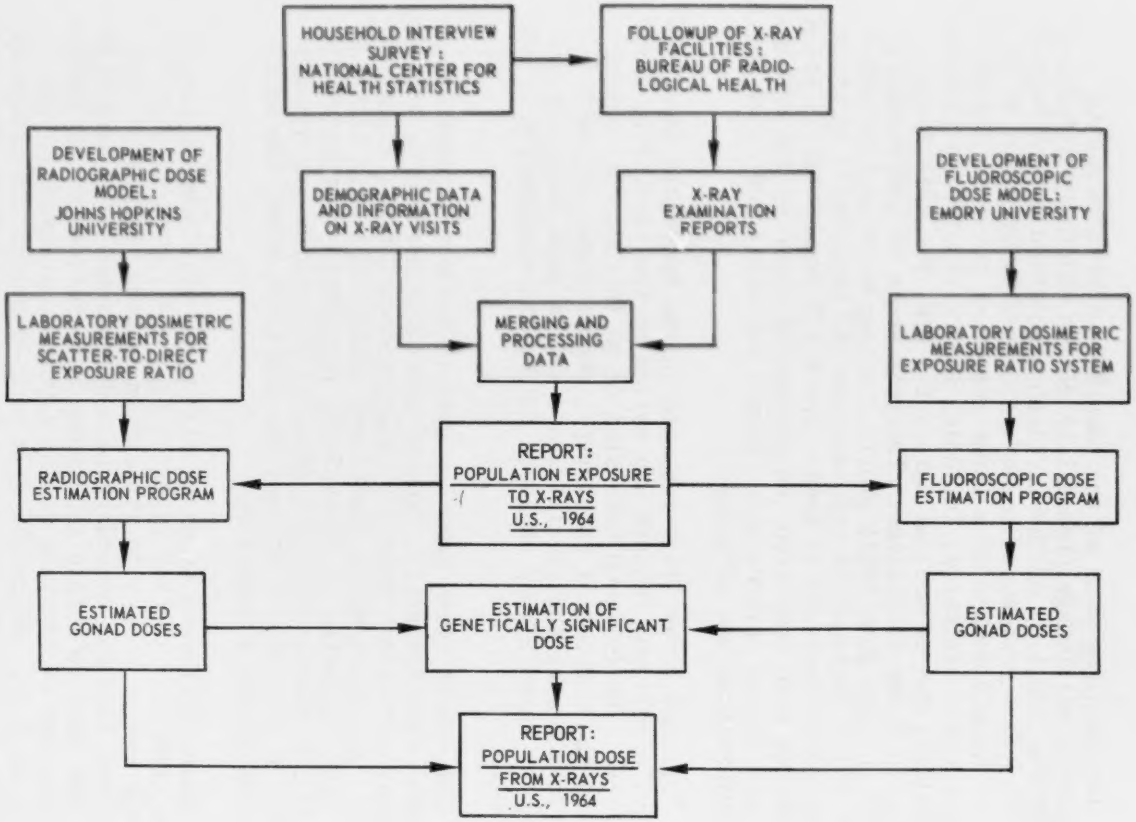
HOUSEHOLD INTERVIEW SURVEY : NATIONAL CENTER FOR HEALTH STATISTICS
FOLLOWUP OF X-RAY FACILITIES : BUREAU OF RADIOLOGICAL HEALTH
DEVELOPMENT OF RADIOGRAPHIC DOSE MODEL: JOHNS HOPKINS UNIVERSITY
DEMOGRAPHIC DATA AND INFORMATION ON X-RAY VISITS
X-RAY EXAMINATION REPORTS
DEVELOPMENT OF FLUOROSCOPIC DOSE MODEL: EMORY UNIVERSITY
LABORATORY DOSIMETRIC MEASUREMENTS FOR SCATTER-TO-DIRECT EXPOSURE RATIO
MERGING AND PROCESSING DATA
LABORATORY DOSIMETRIC MEASUREMENTS FOR EXPOSURE RATIO SYSTEM
RADIOGRAPHIC DOSE ESTIMATION PROGRAM
REPORT: POPULATION EXPOSURE TO X-RAYS U.S., 1964
FLUOROSCOPIC DOSE ESTIMATION PROGRAM
ESTIMATED GONAD DOSES
ESTIMATION OF GENETICALLY SIGNIFICANT DOSE
ESTIMATED GONAD DOSES
REPORT: POPULATION DOSE FROM X-RAYS U.S., 1964

Figure 1. Schematic outline of the X-ray Exposure Study.

Exposure Study; and,

5. the estimation of gonad doses and the genetically significant dose for the U.S. population based on the dosimetric models and the exposure data.

The sampling plan of the household interview survey employed a multistage probability design which permitted a continuous sampling of the civilian population of the United States. This continuous survey collected information about each household member on a large number of personal and demographic characteristics, including topics related to illness, disability, use of medical care (22), and, for this study, visits to X-ray facilities. Thirteen weeks of interviewing (April through June 1964) provided a sample of 10,029 households which included 94 refusals and 282 households in which no one could be found at home. The 9,653 households in which interviews were completed (96 percent of those in the sample) included 31,289 persons about whom X-ray visit and other survey information was obtained.

For each x-ray visit reported in the household interview survey, a followup request was mailed to the identified X-ray facility. The followup consisted of an introductory letter stating the purpose of the survey, report forms for each X-ray procedure at the facility, and a film pack to be exposed using the same factors employed during the examination of the patient.

The report forms were designed to collect information on machine characteristics, type of procedure performed, and the exposure parameters used for radiographic, dental, fluoroscopic, and therapeutic procedures (exhibits 1-4). Although data were collected on therapeutic procedures, estimates of population dose resulting from these procedures are not included in this report because the sample size was too small for statistical reliability.

Three different types of film packs were used to corroborate technical factors reported by the X-ray facilities through use of a sensitometric film packet. Each pack also contained film for recording beam dimensions. A fourth film pack was used to obtain additional information on the surface distribution of exposure during fluoroscopic examinations (exhibits 5-9). Since the film packs provided the estimates of exposure basic to the calculation of gonad dose, they are described in detail below.

Sensitometric Film Packet (exhibit 5)

The purpose of the sensitometric film packet was to permit estimation of exposure in the direct beam without a phantom or human subject.

The basic element was the Eastman Kodak Personnel Monitoring Film Packet, Type 3 (EK-3). Each packet contained a type KK high-speed, nonscreen X-ray film and a commercial nonscreen X-ray film, wrapped in two layers of paper. Mounted on the film packet were discriminator filters. The discriminator filter device consisted of a 0.5 mm lead sheet with four 5/16-inch diameter holes. Hole No. 1 was left open; No. 2 was covered with a one-half-inch square of aluminum 2 mm thick; No. 3 was covered with a half-inch square of copper 0.5 mm thick; and No. 4 was covered with a one-half-inch square of copper 1.5 mm thick. As X-rays penetrated the packet, the metal filters absorbed portions of the X-ray spectrum and the films responded to the radiation in proportion to the energy distributions of the photons incident on the films and the energy dependence of the sensitive emulsions.

Radiographic Film Pack (exhibit 6)

This pack consisted of a prepackaged, high-speed, nonscreen 14- by 17-inch X-ray film (Kodak Royal Blue) backed by a 0.020-inch-thick lead sheet fastened to a flat, polystyrene plastic holder. The sensitometric film packet was mounted at the center of the large film. The holder had four plastic arms pivoted at the corners so that they could be folded for shipping and extended for measuring beam sizes larger than 14- by 17-inches. Four 19-inch strips of 16 mm X-ray film identical to the 14- by 17-inch film were fastened to the backs of the arms. The four arms, the 14- by 17-inch film, and the sensitometric films were embossed with an identification number positioned so that the orientation of each component could be readily reproduced. In the open position, the arms coincided with the diagonals of the 14- by 17-inch film and recorded beams up to a maximum of 48.5 inches.

This pack, with the arms extended, was placed against the cassette holder or on the tabletop (depending upon the examination), so that the central ray of the X-ray beam was directed at the center of the packet. A single exposure was made at the kilovolt peak (kVp), milliamperage (mA), time, and distance as shown for the first exposure on the report form. The arrangement of exposed film strips in exhibit 10 illustrates how the size, alignment, and configuration of the beam were determined.

Dental Film Pack (exhibit 7)

This pack consisted of an 8- by 10-inch prepackaged, nonscreen X-ray film (Kodak Industrial Type M), a lead foil backing attached to cardboard, and a sensitometric film packet centered on the 8- by 10-inch film.

The pack was placed on a flat surface with the tip of the pointer cone positioned at the center of the package over the "bulls-eye." The film pack was exposed for 3 seconds, using the same cone, kVp, and mA as reported by the dentist for the first exposure of the examination.

Dual-Fluoroscopic Film Pack (exhibit 8)

This pack consisted of a 14- by 17-inch X-ray film (Kodak Royal Blue) and an 8-by 10-inch high-speed, nonscreen X-ray film (Ansco High Speed Monopack), which was held perpendicular to the 14- by 17-inch film by a 3-inch-long stainless steel bracket. The sensitometric packet was centered under the steel bracket. On exposure, the image of the bracket was projected on the 8- by 10-inch upright film, and the angle of divergence of the image was measured to estimate the source-to-tabletop distance of the fluoroscopic tube.

To use the film pack, the practitioner was requested to place the 8- by 10-inch film in the bracket, center the pack on the tabletop over the fluoroscopic X-ray tube, and, with the shutters at their maximum opening, expose the pack for 15 seconds, using the same kVp and mA as reported for the examination of the patient.

Fluoroscopic Record Film Pack (exhibit 9)

This pack consisted of two 14- by 17-inch units hinged together. Each unit contained two prepackaged, nonscreen X-ray films, one high-speed (Kodak Type KK) and the other slow (Kodak Commercial). These were the same emulsions employed in the sensitometric packet. This pack was designed to be used during a fluoroscopic examination similar to that reported in the household survey. The practitioner was asked to unfold and fasten the pack to the tabletop, mark the location of the patient's pubic symphysis and sternal notch on the cover, and then proceed with the examination. The pack effectively recorded X-ray exposure over an area 14-inches wide and 34-1/2 inches long.

Chapter 2

ESTIMATION OF GONAD DOSE FROM RADIOGRAPHIC EXAMINATIONS

Chapter 2

ESTIMATION OF GONAD DOSE FROM RADIOGRAPHIC EXAMINATIONS

INTRODUCTION

The X-ray Exposure Study was designed to provide basic data about each X-ray examination reported by sample respondents. The method of obtaining exposure data using report forms and film packs (*21*) may be characterized as an "indirect" method, since measurements were not made directly on patients undergoing radiologic examinations. This approach offered several advantages including a broader coverage of variations in radiologic techniques and patient characteristics than was possible by direct monitoring of individual examinations. Also, it was felt that reporting of technical factors used rather than actual monitoring of the examination would reduce a possible tendency for the practitioner to use optimum rather than usual techniques for the sample examination.

In order for these basic data to be used to estimate the Genetically Significant Dose (GSD), the application of several models was required. Estimates of gonad dose from radiographic and dental examinations required the development of a model to estimate skin exposure as a function of reported technical parameters (*21*). A dose model was also developed from which the gonad dose could be estimated from a knowledge of the exposure to any portion of the body. These models are described below. The use of varying film sizes during fluoroscopy required the development of a specific model for estimating gonad dose from these examinations. This model is described in chapter 3.

EXPOSURE MODEL

A complete description of the exposure model developed for the X-ray Exposure Study may be found in the earlier report

(*21*). The data on the exposure parameters used for each examination in the study were the basis for the development of all exposure estimates. The report form provided information on film size, kilovolt peak, milliamperage, exposure time, and target-to-film distance for each separate film. Also reported was information about the X-ray unit, including waveform and filtration in the useful beam. The film pack provided an estimate of the beam dimensions from which the ratio of beam size to film size for that film could be calculated. This procedure is discussed in detail in an earlier paper (*23*).

Data on exposures were developed from the measured film pack values and the associated technical factors reported by the X-ray facilities. These data were reduced by eliminating examinations in which the reported total filtration was less than 0.6 or greater than 4.5 millimeters of aluminum equivalent, the reported kilovolt peak was less than 40 or greater than 100, or a discrepancy had been noted between the calculated exposure value and that derived from the film pack.

The data on the remaining sample of approximately 1,500 cases were analyzed according to the type of equipment through a series of multiple regressions. This approach suggested an exposure model whose surface appeared to be exponential in one direction and quadratic in the other. The multiple regression approach accommodated the model by approximating the exponential segment in terms of a power series while applying directly to the quadratic portion. The model yielded the following equations:

Dental:

$$\begin{aligned} Z = {} & 74.402127 - 131.415127X + 2.395770Y + 30.865804X^2 \\ & + 0.928925XY - 0.038933Y^2 - 3.391479X^3 + 0.024723X^2Y \\ & - 0.009086XY^2 + 0.000324Y^3 \end{aligned}$$

Nondental:

$$\begin{aligned} Z = {} & -60.865618 - 36.230728X + 4.825809Y + 18.314219X^2 \\ & - 0.916140XY - 0.037316Y^2 - 2.352214X^3 + 0.111286X^2Y \\ & - 0.000466XY^2 + 0.000219Y^3 \end{aligned}$$

where,

X = Total filtration,
Y = Kilovolt peak, and
Z = Milliroentgens per milliampere-second (mR/mAs) at 12 inches.

Values generated by these equations are shown in exhibits 11 and 12. The equations can generate values for any combination of kVp and filtration; however, the reliability of the equations is restricted to the range of factors included as input to the model.

For the dental equation, the mean input values were 2.35 for total filtration and 68.5 for kVp. The mean exposure was 40.3 mR/mAs with a standard deviation of 17.2. These may be compared with similar statistics for the nondental equation in which the mean filtration was 2.67, kVp was 73.2, and the mean mR/mAs was 43.9 with a standard deviation of 22.6. Based on standard deviations associated with the mean kVp at the 95 percent confidence level, the dental equation had a usable range of approximately 50 to 90 kVp, the nondental equation 45 to 100 kVp.

The calculation of estimated exposure at the skin utilizing these equations included the reduction of reported source-to-film distance by the body part thickness based on the reported type of examination, projection, and patient characteristics (exhibit 13).

Estimated mean exposures at the skin derived from the exposure model are shown in exhibits 14 and 15 for selected types of examinations.

FACTORS AFFECTING DOSE[1]

The factors which influence the dose received by any specific tissue of the body during medical X-ray exposure may be divided into two general categories: anatomical and physical. The influence of a particular factor depends upon whether the radiation has reached the tissue directly from the X-ray tube or whether it has been scattered from an adjacent structure.

Of the anatomical factors affecting dose, the location of the field of irradiation with respect to the tissue in question is of major importance. The depth of the tissue also has a marked influence on radiation dose. When the tissue falls within the limits of the useful beam, the attenuation of the dose due to depth is of significance. Other factors affecting dose include the volume and density of the irradiated structure, the distribution of body mass, and the atomic composition of the specific tissue. In each case, the dose relationships are quite complex.

---

[1] The material in this and the following three sections is adapted from an unpublished Progress Report, Research Grant (RH-00085). This report entitled "Dose Distributions in Diagnostic X-ray Procedures" by Dr. Russell H. Morgan, was submitted to the National Institutes of Health on September 30, 1963.

The principal anatomical factors affecting radiation dose include the distance from the field of irradiation to the tissue of interest, the position of the tissue below the surface of the body, the volume of the irradiated field and the distribution of body mass. The model for dose estimation must permit a thorough evaluation of each of these factors as it affects dose.

DOSE MODEL

Anatomical Factors

The distance between an irradiated field and any tissue of interest varies with the height of the subject. To some extent, height also governs the distribution of body mass. Hence, the model used patient height as a primary variable for dose determination.

The depth at which any tissue lies below the surface of the body is a function of body width or thickness. Body width and thickness also govern the volume of the irradiated field and are related to the distribution of body mass. For individuals of a given height, body width and thickness are closely related to subject weight. Therefore, weight was used as a second determinant in the dose model.

Height data for the study population were classified into six categories. For each height category, weight intervals were chosen such that a regularly progressive series was obtained overlapping from one height category to another and extending through a broad range of weight values. Thirty individuals selected to match the heights and weights of the study population were used to obtain the dosimetric data for this model. The anthropometric characteristics of the thirty individuals selected are shown in exhibit 16.

Physical Factors

Nine major physical factors in the technique of diagnostic radiography affect radiation dose. Each factor was examined through a range of values consistent with those encountered in diagnostic medical X-ray practice. Simple relationships are known to exist between dose and the X-ray tube current (mA), the exposure time, and the distance between the target of the X-ray tube and the entrance surface of the patient. Radiation dose is directly proportional to each of the first two and bears an inverse-square relationship to the third. The collection of dosimetric data through multiple ranges of tube current, exposure time and target-to-film distance, was therefore unnecessary since all measurements were normalized to a reference exposure, considered to be one roentgen measured in the center of the useful beam in the absence of scattering media at the tabletop on which the subjects were irradiated.

The factors of X-ray tube potential, waveform, and beam filtration affect dose because of their controlling influence on the intensity and quality of the primary beam. These factors were not studied separately to obtain a measure of their effect on radiation dose. Instead, several combinations of kilovoltage and filtration were selected to yield radiation qualities covering the range of beam qualities commonly used in diagnostic medical X-ray practice. The range of beam qualities used in diagnostic radiology extends from a half-value-layer of approximately 0.5-mm of Al equivalent for low kVp techniques to 8.0-mm of Al equivalent for examinations conducted at about 150 kVp. This range is relatively small by comparison with X-ray therapy or industrial applications. Dosimetric measurements were made with a constant potential waveform at half-value-layers of 1-, 2-, 4- and 8-mm of Al equivalent.

During a radiological examination, the angle at which radiation is projected varies widely. Generally, the X-ray beam is perpendicular to the long axis of the body in an antero-posterior, postero-anterior, or lateral direction; oblique projections are also frequently used. Under some circumstances, particularly in radiography of the skull, the radiation is projected at angles not perpendicular to the long axis of the body. However, the model for dose estimation was limited to perpendicular projections, since most projections are in this direction. Because of body symmetry, the dosimetry was limited to five projections. The specific angulations adopted for study included the antero-posterior, the postero-anterior, the right lateral, and the left anterior and right posterior oblique (45° from the sagittal plane) projections.

An examination of the factors of field position and field size reveal a more complex situation. In diagnostic X-ray practice, radiation fields not only vary in location and size, but range widely over the surface of the body. Dose values vary considerably with changes in the distance between any tissue selected for computation of dose and the irradiated field. Classification of these parameters is difficult and involves the delivery of large numbers of exposures to each individual on whom measurements are made.

Actually, however, an exposure system was devised which allowed the evaluation of the influence of field size and position on radiation dose without the need for a large number of such exposures. This system was based on the following concept: when an individual receives an X-ray exposure of given radiant energy per unit area, the dose received by any tissue is the same whether the field of irradiation is exposed all at once, or is divided into a number of incremental areas each of which is separately exposed one after the other until the entire field is irradiated. This principle was applied in this study by setting up an X-ray system in which the conventional fixed-field X-ray beam was replaced by a moving beam of small dimensions (that is, 2- by 2-cm at the tabletop) which systematically scanned each subject from side to side and from head to foot. For each exposure of a 2- by 2-cm area, the tissues within the body received a small but finite dose. Detectors recording in digital format were placed at locations of interest. The use of a computer with magnetic tape capabilities made possible the instantaneous recording of each exposure as it was generated. This procedure was used to estimate doses produced by fields of any size and position. In order to determine the exposure received by a tissue of interest from a field of given size and position, the recorded exposures from each contributing 2- by 2-cm area were summed over the exposed field. By the use of sensitive dosimetric equipment, the system delivered a whole-body dose of no more than 20 millirads to each subject studied.

EXPERIMENTAL SETUP

The exposure facilities designed for this study are shown in exhibit 17. On the left is the scanning X-ray system, consisting of an exposure table and an overhead X-ray tube carriage. The carriage occupies a position 1.2 meters above the table surface and carries a conventional heavy-duty, diagnostic-type, rotating anode X-ray tube, mounted with its long axis parallel to that of the table. A leaded cylinder, 18 inches in diameter surrounds the tube and is mounted on roller bearings which permits it to rotate coaxially about the tube target. Ten ports are located at 36° intervals around the periphery of the cylinder in a plane passing through the tube target. Each port projects a beam of radiation 2- by 2-cm on the table below. As the cylinder rotates, the beam moves from side to side across the table.

The X-ray tube carriage is mounted on roller bearings in a track parallel to the long axis of the table. It is driven by an electric motor which, through an appropriate gear chain, also rotates the leaded cylinder around the X-ray tube. When a subject is positioned on the table and the X-ray tube energized, the subject is scanned with an X-ray beam moving from side to side and from head to foot as the carriage moves the length of its track above the exposure table.

Detectors were placed at seven locations: one in the region of the male gonads, one each above and below the abdomen, one each above and below the thorax and one each above and below the head. All detectors except that at the male gonads were oriented vertically to the tabletop for all projections; those located beneath the subject were below the tabletop. The male gonadal detector was oriented perpendicular to the coronal plane for all projections; that is, as the subject was rotated, the probe was correspondingly rotated. Only data from the detectors above the abdomen and at the male gonads were necessary for estimation of gonad dose.

Although detectors should theoretically have been placed at each tissue of interest, this approach was not practicable with living subjects. However, it was known from experience in radiation therapy that the dose to a tissue at depth can be determined from known values of the exposure at the points of entrance and exit. Detectors were, therefore, placed at selected intervals over the body surface so that dose values at depth could be computed, given the number of intervals and that mapping of the surface exposure fields was essentially complete.

Three of the detector probes used to collect exposure data are shown in exhibit 17. These detectors are of the tissue-equivalent, crystal-photomultiplier type and are mounted with their long axis perpendicular to the table surface. A lead shield in the upper end of each probe prevented the direct beam from entering the probe.

The output signals of the several probes were generated in digital form. That is, the signals consisted of a series of pulses of identical amplitude with each pulse representing the measurement of an exposure whose value depended on the sensitivity of the probe. The probes used in this system had sensitivities between 10^{-7} and 10^{-8} roentgens per pulse. The precision of such devices was relatively unaffected by the number of decades to be covered. The digital form of data recording also facilitated the later processing of the recorded exposure data.

The exposure data obtained from this system were in the form of 600 X-ray scans (20 scans on each of 30 individuals) covering a wide range of patient and physical variables. Each scan consisted of a matrix of 3,000 2- by 2-cm cells. The response of each detector was recorded as each cell was exposed. Each matrix covered an area 60 cm in width and 200 cm in length corresponding to the dimensions of the tabletop. The scattered exposures recorded at each probe were expressed as a ratio to the reference exposure (one roentgen delivered to the tabletop in the absence of a subject). These ratios are termed "scattered-to-direct ratios." A fuller description of the matrices and selected values will be published in a forthcoming report.

DOSE CALCULATION SYSTEM

Data derived from the experimental system described above were used to calculate estimates of gonad exposure and dose from medical radiographic procedures reported in the X-ray Exposure Study. An estimate of gonad exposure for any given film was obtained by choosing the X-ray scan matrix representing most closely the characteristics of the patient examined and the physical factors used to expose the film. By means of a digital computer, the scattered-to-direct ratios were summed over those cells of the selected matrix located within the irradiated field. This sum represented that portion of the gonadal exposure attributable to scattered X-rays. For films in which the gonads were estimated to lie within the irradiated field, total gonadal exposure was calculated by adding scattered and direct exposure values. For examinations in which the gonads were estimated to lie outside the irradiated field, the gonad exposure was the sum of scattered exposure values, since the direct exposure was zero. Estimates of exposure were converted to absorbed dose by use of a constant factor. For purposes of estimation of gonad exposure, data from two detectors were used. One was located above the subject in the region of the trans-ovarian plane and the other adjacent to the male gonads.

In order to estimate ovarian exposure, it was necessary to produce matrices which simulated the internal placement of a detector at the depth of the ovaries. Various thicknesses of pressdwood were scanned with a probe located at a depth corresponding to the position of the ovaries. An additional detector was positioned on the surface of the phantom directly above the probe at depth. Matrices were then generated in which values of scattered exposure at depth were expressed as a ratio to scattered exposure on the surface. Matrices of this type were prepared for phantom thicknesses of 15, 20, 25, 30, and 35 centimeters.

The ovarian scattered-to-direct matrices for each subject were produced by choosing a depth-to-surface scattered matrix which matched the subject's abdominal thickness. The depth-to-surface scattered ratios were then multiplied cell by cell by the surface scattered-to-direct ratios. This resulted in a new matrix whose cells contained a ratio of the scattered exposure received at the ovarian location to the direct exposure received at the tabletop. This procedure was done separately for right and left ovaries for each subject and yielded a series of depth-exposure matrices for all projections and half-value-layers.

Since the examinations reported in the X-ray Exposure Study encompassed a continuous range of beam qualities as measured by half-value-layer, it was necessary to interpolate the scattered-to-direct ratios for intermediate values of half-value-layer. An investigation of the relationship between the scattered-to-direct ratios and half-value-layer was done by scanning phantom material of varying thickness with X-ray beams of various qualities. Analysis of these data indicated that the functional relationship between beam quality and the scattered-to-direct ratios was nonlinear and dependent upon the distance between the probe and the exposed matrix cell. The nonlinearity of the data was corrected by a logarithmic transformation which also significantly simplified the calculation for the effect of varied distances.

The expression used to interpolate the exposure ratios for intermediate half-value-layers is:

$$R_n = E \ (\log R_c + 0.8 \frac{\log (HVL_n)}{\log (HVL_c)}$$

where,

R_n = interpolated exposure ratio,

E = surface exposure,

R_c = exposure ratio in the matrix cell,

HVL_n = half-value-layer reported in the X-ray Exposure study, and

HVL_c = half-value-layer associated with the matrix being used.

In order to use this relationship, the scattered-to-direct ratios were converted to logarithms to the base 10.

In the gonad dose estimation program each reported film was matched with the scan most nearly approximating the reported physical factors and anatomic characteristics associated with the film. Using an assumed center of interest of the film, the estimated field size and beam center were located on the matrix. The top, bottom, left, and right limits of the irradiated field were then established according to matrix rows and columns.

The calculation of gonad dose consisted of the following steps:

1. The half-value-layer interpolation was performed for each cell and the result converted to arithmetic form.

2. Exposure ratios were summed over all cells lying within reported limits of the irradiated field.

3. The sum of the ratios was then multiplied by the reported direct exposure, yielding an estimate of gonad exposure due to scattered radiation.

4. When the gonads were estimated to lie within the limits of the irradiated field, the direct exposure, attenuated for depth, was added to the scattered exposure, yielding an estimate of total exposure to the gonads.

5. The estimated total exposure was converted to estimated absorbed dose by means of the relationship:

$$AD = 0.94 \cdot E. \quad (24)$$

Dose estimates were calculated for each film reported, separately for right and left ovary locations and for the testes.

EVALUATION OF DOSE MODEL

Direct measurements of exposure for a set of 500 medical radiographic examinations were used to evaluate the dose model. Estimates on per film, per examination, and mean exposure bases were used for the comparison of measured and estimated exposure. The examinations used for this test were performed at the Department of Radiology of the Hospital of the University of Pennsylvania and were drawn from the regular workload of the Department. For each examination included in this test series, information identical to that collected in the X-ray Exposure Study was obtained. This information was processed using the same procedures as those used for the X-ray Exposure Study to produce exposure estimates for input to the dose model. During the radiographic examination, measurements of exposure were made at the testes and on the abdominal surface at the approximate ovarian level. The data from these measurements were used for comparison with the calculated exposure estimates generated by the dose model.

The series of examinations used for the test were selected by age, sex, and type of examination. Height and weight were not used as criteria for selection since these could be expected to be reasonably distributed with age and sex.

Seventeen specific types of examinations were included in the test series. These represented the bulk of those reported in the X-ray Exposure Study and those comprising the outpatient workload of the Department of Radiology of the Hospital of the University of Pennsylvania.

Both powder and cleaved crystal types of lithium fluoride thermoluminescent dosimeters were used for the direct exposure measurements. These dosimeters had favorable energy dependent characteristics for the diagnostic X-ray region and could detect exposures as low as 5 mR. In addition they were small in size, could be easily transported, required no power source, and were radiolucent.

Estimates of mean exposure derived from the dose model are compared with the mean direct measurements of exposure in table 1. Mean surface abdominal exposures are based on single films, usually the first of an examination; the mean testicular exposures are based on all films for an examination. The number of examinations included in each category is also shown in table 1.

For those examinations in which the ovaries might be expected to be in the irradiated field (hips and pelvis, barium enema, gall bladder, upper gastro-intestinal, intravenous pyelogram, abdomen and lumbar spine), the percent differences between exposure means based on the abdominal dosimeter and those based on the dose model ranged from -29.5 percent for the intravenous pyelogram examination to + 56.6 percent for the barium enema. A greater variability was observed for examinations where the ovaries might be expected to be outside the irradiated field. The mean exposure levels for these examinations are usually below 5 mR in contrast with a mean exposure of about 600 mR when the ovaries are located within the beam. Estimates for testicular exposure follow much the same pattern.

Data suggest that the reliability of thermoluminescent dosimeters may be about ± 20 percent at low dose levels (below 10 mR) with a greater reliability at higher exposure levels. The data in table 1 indicate that an additional source of variability may have been present to produce the mean differences found. A review of the test procedures and assumptions indicates a probable source of error arising from small discrepancies in dosimeter placement.

Table 1. Comparison of dosimetry and system exposure estimates, radiographic dose estimation system

Type of examination	Estimate method[a]	Number of cases	Mean abdominal surface exposure	Mean testicular surface exposure
			(Milliroentgens)	
Hips and pelvis	D	17	627	832
	S		650	1,008
Percent difference[b]			+ 3.7	+ 21.2
Barium enema	D	14	511	911
	S		800	504
Percent difference			+ 56.6	- 44.7
Gall bladder	D	13	516	8
	S		554	1
Percent difference			+ 7.4	- 87.5
Upper gastro-	D	33	501	32
intestinal series	S		664	17
Percent difference			+ 32.5	- 46.9
Intravenous pyelogram	D	25	719	1,876
	S		507	1,443
Percent difference			- 29.5	- 23.1
Abdomen	D	17	704	112
	S		729	302
Percent difference			+ 3.6	+ 169.6
Lumbar spine	D	17	606	738
	S		599	216
Percent difference			- 1.2	- 70.7
Lower extremities	D	39	1	1
	S		-	[c]9
Percent difference			---	[c]+ 800
Upper extremities	D	28	1	1
	S		2	-
Percent difference			---	---
Thoracic spine	D	9	74	9
	S		91	4
Percent difference			+ 23.0	- 55.6

Table 1. Comparison of dosimetry and system exposure estimates, radiographic dose estimation system — continued

Type of examination	Estimate method[a]	Number of cases	Mean abdominal surface exposure	Mean testicular surface exposure
			(Milliroentgens)	
Ribs	D	9	115	2
	S		165	-
Percent difference[b]			+ 43.5	---
Chest (photofluorographic)	D	35	14	2
	S		10	-
Percent difference			- 28.6	---
Chest (radiographic)	D	32	5	1
	S		4	-
Percent difference			- 20.0	---
Shoulder	D	11	3	1
	S		-	-
Percent difference			---	---
Cervical spine	D	16	2	2
	S		-	-
Percent difference			---	---
Sinuses	D	14	1	1
	S		-	-
Percent difference			---	---
Skull	D	31	1	2
	S		-	-
Percent difference			---	---

[a] D = dosimetry estimate; S = system estimate.

[b] Difference between means expressed as percentage of the mean based on dosimetry.

[c] Includes one case with unusually high system estimate.

Chapter 3

ESTIMATION OF GONAD DOSE FROM FLUOROSCOPIC EXAMINATIONS

Chapter 3

ESTIMATION OF GONAD DOSE FROM FLUOROSCOPIC EXAMINATIONS

INTRODUCTION[1]

The previous chapter presented a model for the estimation of gonad dose from medical radiographic examinations. This model assumes a definable irradiated field and essential homogeneity of exposure across the field.

During a fluoroscopic X-ray examination, the exposure pattern on the patient is complex due to changes during the examination in field size and location. Measurements of surface exposures were obtained in the X-ray Exposure Study from the fluoroscopic record film pack placed between the patient and the tabletop during actual fluoroscopic examinations (Ch. 1 and exhibit 9). All films were developed under highly controlled time and temperature conditions. Densitometric readings of these films were made using a 3- by 3-cm grid system. Estimates of exposure in milliroentgens were calculated for each grid cell based on calibration of the film. The exposure pattern was then displayed for each examination in tabular format oriented to the patient. This chapter describes the model which was used to obtain estimates of gonad dose from these surface exposure data. The model was based on an experimental determination of the ratio of gonadal exposure to direct exposure which would result from a known exposure to any 3- by 3-cm surface area. Estimates of gonad exposure and dose were calculated based on these ratios and the known exposure pattern derived from the X-ray Exposure Study for each fluoroscopic examination.

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[1] The system described in this chapter for estimating gonad dose from fluoroscopic examinations was developed by Dr. Heinz Stephen Weens, and associates at the Emory University School of Medicine, Atlanta, Georgia, under Contract PH-86-66-58. The material in this chapter was abstracted, in part, from the final report of that contract.

DOSE MODEL

All measurements for the determination of exposure ratios were made using a RANDO[2] phantom. A grid system to permit alignment of surface exposure data to the exposure ratios was attached both to the left side and the rear of the phantom, as shown in exhibits 18 and 19. Three holes were bored in the phantom to permit insertion of small Sloan-Kettering (25) ionization chambers at the approximate gonadal locations.

The postero-anterior grid system was located against the back of the phantom (exhibit 18); the left lateral grid was located against the left side (exhibit 19). Both grid systems consisted of 198 3- by 3-cm cells arranged in 18 rows of 11 cells each.

A General Electric diagnostic X-ray unit equipped with a Dynamax "42" X-ray tube was fitted with a special collimator so that individual 3- by 3-cm cells on the surface of the phantom could be exposed. The output of the unit was continuously monitored by a Victoreen ratemeter probe placed within the collimator (exhibit 20) in order to measure the exposure applied to each cell and to assure a constant exposure rate. The exposure rate at the probe was converted to the exposure rate to the surface of the phantom using a calibrated Victoreen Condenser R-meter.

Exposures to each cell of the grid system were made at half-value-layers of 1-, 2-, and 4-mm of Aluminum equivalent. During the irradiation of each cell, exposure at the three gonadal locations was determined by means of the implanted ionization chambers. A sufficient exposure was given to the surface of each cell to produce a readable value on each gonadal detector. This process was repeated, and the gonadal exposure recorded was the average of these two independent measurements.

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[2] Alderson Research Laboratories, Inc., Stamford, Connecticut.

For each cell of the grid system, exposure ratios were calculated for each beam quality and for each of the gonadal locations using the following relationship:

$$\text{Exposure Ratio} = \frac{\text{Exposure at Gonadal Dosimeter}}{\text{Surface Exposure at Given Cell.}}$$

DOSE CALCULATION SYSTEM

For each fluoroscopic examination in the X-ray Exposure Study, the surface exposure was reported in the form of a 3- by 3-cm grid pattern similar to the one used to expose the phantom. A specific cell on each examination grid pattern was identified as that corresponding to the inferior margin of the pubic symphysis. Although the distance between the symphysis pubis and the gonads varied according to the physical characteristics of each patient in the Study, it was not possible to replicate this variability in the model. For purposes of dose estimation constant distances were assumed between the level of the symphysis pubis and the ovarian and testicular locations. The distances assumed were based on published data (*1, 12-14, 26*) and on unpublished data based on gynecological film studies provided by the Clinical Center of the National Institutes of Health (exhibit 21). These distances determined the location of the detectors in the RANDO phantom and consequently are reflected in the exposure ratios. By registration of the indicated location of the symphysis pubis on the exposure grid pattern with the analogous location on the phantom grid reference system, the gonadal locations for each individual patient were approximated.

The exposure at each gonad site (E_j) was calculated using the appropriate exposure ratios (ER_{ij}) and the recorded exposure to each grid cell of the surface exposure chart (SE_i) according to the following formula:

$$E_j = \sum_{i=1}^{198} (ER_{ij} \cdot SE_i)$$

where,

i indexes cell,

j indexes the gonad site (right ovary, left ovary, and testes).

This formula defines the exposure at the jth gonad site as the summation over all surface exposure cells of the product of the exposure ratio in the ith cell times the recorded exposure to the body surface in that cell location. Estimates of gonad exposure (E_j) were calculated separately for the postero-anterior (PA), left-lateral (LL) and right-lateral (RL) positions for each of the three selected half-value-layers.

The film used to record the pattern of exposure during each examination remained in a fixed plane relative to the X-ray tube. Consequently, the exposures recorded represented the summed effect of exposure time spent in all positions. In order to estimate gonad exposure for each fluoroscopic examination, it was necessary to take into account the percentage of total examination time in each patient position. Exposure estimates were computed separately as if the total exposure time had been in each of the three projections (PA, LL, RL). Time in the postero-anterior position was defined to include time spent in all positions other than right- or left-lateral. Although a right-lateral exposure ratio grid was not produced using the phantom, a simulated right-lateral grid was derived by symmetric rotation of the left-lateral grid.

Estimated gonad exposure was calculated using the following equation:

$$E = (tE)_{PA} + (tE)_{LL} + (tE)_{RL}$$

where,

E is the exposure for any gonad site,
t is the fraction of examination time reported in any position,
PA is the postero-anterior position,
LL is the left-lateral position, and
RL is the right-lateral position.

Gonad exposure values were calculated for half-value-layers of 1-, 2-, and 4-mm of Al equivalent. Gonad exposure values for other HVL's were calculated by linear interpolation or extrapolation according to the following equations:

For half-value-layers less than 2-mm Al equivalent,

$$E_{HVLX} = E_{HVL1} + (\mathrm{HVLX} - 1)\left(\frac{E_{HVL2} - E_{HVL1}}{\mathrm{HVL2} - \mathrm{HVL1}}\right)$$

For half-value-layers greater than 2-mm Al equivalent,

$$E_{HVLX} = E_{HVL2} + (\mathrm{HVLX} - 2)\left(\frac{E_{HVL4} - E_{HVL2}}{\mathrm{HVL4} - \mathrm{HVL2}}\right)$$

where,

E_{HVLX} = the exposure for a half-value-layer of X-mm Al equivalent.

The surface exposure data based on the fluoroscopic record film pack included backscatter to the film from the patient and the tabletop. Since the surface exposures used in the calculation of the exposure ratios were measured in air, correction for backscatter was required in the resultant gonad exposure estimates. It was assumed that backscatter was uniform across the entire irradiated field. An adjustment factor of 0.74 was experimentally derived from a comparison of exposure data made with and without a backscattering medium for 10 simulated fluoroscopic examinations, and applied to all estimates of gonad exposure.

The final gonad exposure estimate was converted to an estimate of absorbed dose (AD) by the following relationship:

$$AD = 0.94 \cdot E$$ (*24*)

EVALUATION OF THE DOSE MODEL

A series of tests was carried out to evaluate the fluoroscopic dose model. For these tests a fluoroscopic X-ray unit was programmed to replicate, on a second-by-second basis, the parameters of a previously recorded fluoroscopic examination (*18, 27*). At each second, the status of the X-ray tube (energized or off), tube current, kilovoltage, position of the shutters, and location of the beam was reproduced. Fifteen fluoroscopic examinations were replicated using the RANDO phantom with dosimeters implanted in the gonadal locations. A fluoroscopic record film pack identical to those used in the X-ray Exposure Study was placed under the phantom during each simulated examination. These exposed film packs were processed and the resulting data used as input to the dose model. Exposure estimates produced by the model were then compared with those determined dosimetrically during the simulated fluoroscopic examination. Ten barium enema and five upper gastrointestinal examinations were replicated. The latter five were also repeated for PA and LL exposures separately, thus producing a total of 25 sets of estimates for comparison.

Twenty-five dosimetric measurements were produced for each of the gonadal locations for comparison with the dose model estimates for these same sites. These data are shown in table 1. The comparisons are expressed as a ratio of the model exposure estimate (E_m) to the dosimetrically determined exposure (E_d). From these data, mean values of the ratio (E_m/E_d) were calculated for the right and left ovarian locations, and for the testicular location. Since there was no significant difference between the means of the ratios for the two ovarian sites (right ovary = 1.41; left ovary = 1.44), these values were grouped for analysis, and a single mean value of the ratio E_m/E_d was calculated for the combined ovarian locations. The mean of the ratios E_m/E_d for the 50 ovarian values was 1.43 ± 6 percent; the corresponding mean for the 25 testicular values was 0.75 ± 18 percent. The errors associated with these and the following mean ratios are standard errors of the mean.

An inspection of the E_m/E_d ratios for ovarian exposures indicated an apparent clustering of the ratio values for model exposure estimates above 100 mR and another clustering for lower exposure estimates. Using 100 milliroentgens as a basis for separating the data into two groups, a mean for each group was calculated. For model exposure estimates less than 100 mR the mean of the ratio was 0.95 ± 7 percent. For estimates greater than 100 mR the mean was 1.90 ± 4 percent. A similar analysis of the testicular exposure ratios resulted in a mean of 0.37 ± 28 percent for model estimates less than 20 mR and 1.56 ± 9 percent for estimates greater than 20 mR.

Results of the test procedure implied that the dose model may overestimate for relatively high exposure examinations and underestimate for low exposure examinations. A review of the dose model suggested several possible sources for this variability. When the results of duplicate film exposures were compared with each other, the mean value of the ratios for 27 paired film exposure estimates ranging from 10 to 4000 mR was 1.00 ± 3.7 percent. Since the duplicate films were aligned to the exposure ratio table in an identical manner, it was assumed that no alignment error was introduced into this comparison. Thus, any deviation from a 1:1 correspondence was due only to errors introduced by the film, the exposure, the film development, and the densitometric reading. It is unlikely that these factors or any associated with the X-ray generator or the fluoroscopic simulator introduced a large error into the model

Table 1. Comparison of dosimetry and system exposure estimates, fluoroscopic dose estimation system

				Kilovolt peak 90		
					Exposure time in seconds	
Estimate method	Right ovary	Left ovary	Testes	Milliamperage	Postero-anterior	Left-lateral
	(Milliroentgens)					
Barium Enema						
Dosimetry	150	138	25	1.0	123	0
System	271	263	17.3			
Ratio[a]	1.81	1.91	0.69			
Dosimetry	287	263	48	2.5	123	0
System	541	492	32			
Ratio	1.89	1.87	0.67			
Dosimetry	362	259	10	1.0	158	0
System	539	418	18.3			
Ratio	1.49	1.61	1.83			
Dosimetry	691	494	19	2.5	158	0
System	1,154	1,036	38			
Ratio	1.67	2.10	2.00			
Dosimetry	427	180	18	1.0	181	0
System	496	299	24.3			
Ratio	1.16	1.66	1.35			
Dosimetry	927	390	39	3.0	181	0
System	1,413	969	70			
Ratio	1.52	2.48	1.79			
Dosimetry	80	56	10	1.0	239	0
System	47	45	2			
Ratio	0.59	0.80	0.20			

Table 1. Comparison of dosimetry and system exposure estimates, fluoroscopic dose estimation system — continued

Estimate method	Right ovary	Left ovary	Testes	Kilovolt peak 90		
					Exposure time in seconds	
	(Milliroentgens)			Milliamperage	Postero-anterior	Left-lateral
Barium Enema						
Dosimetry	174	123	22	3.0	239	0
System	340	309	17			
Ratio	1.95	2.51	0.77			
Dosimetry	1,050	479	25	1.0	398	0
System	1,505	863	42			
Ratio	1.43	1.80	1.68			
Dosimetry	2,006	914	48	2.5	298	0
System	3,507	1,669	83			
Ratio	1.75	1.83	1.73			
Gastrointestinal Series						
Dosimetry	39	28	20	1.0	157	111
System	30	32	4.5			
Ratio	0.77	1.14	0.23			
Dosimetry	73	66	28	2.0	185	71
System	100	91	8			
Ratio	1.37	1.38	0.29			
Dosimetry	972	425	46	2.0	203	43
System	1,675	806	75			
Ratio	1.72	1.90	1.63			
Dosimetry	69	46	42	2.0	221	91
System	83	63	11.3			
Ratio	1.20	1.37	0.27			

Table 1. Comparison of dosimetry and system exposure estimates, fluoroscopic dose estimation system — continued

				Kilovolt peak 90		
					Exposure time in seconds	
Estimate method	Right ovary	Left ovary	Testes	Milli-amperage	Postero-anterior	Left-lateral
	(Milliroentgens)					
Gastrointestinal Series						
Dosimetry	48	41	24	2.0	85	131
System	30.4	28.4	10.9			
Ratio	0.63	0.69	0.45			
Dosimetry	12	19	10	1.0	157	0
System	25.5	26	2.3			
Ratio	2.13	1.37	0.23			
Dosimetry	10	30	10	1.0	0	111
System	8	7.5	0.4			
Ratio	0.80	0.25	0.04			
Dosimetry	49	49	18	2.0	185	0
System	70	63	3.5			
Ratio	1.43	1.29	0.19			
Dosimetry	14	30	10	2.0	0	71
System	17.5	16.5	1			
Ratio	1.25	0.55	0.10			
Dosimetry	838	360	25	2.0	203	0
System	1,115	715	41.5			
Ratio	1.33	1.99	1.66			
Dosimetry	134	65	21	2.0	0	43
System	466	164	14			
Ratio	3.48	2.52	0.67			

Table 1. Comparison of dosimetry and system exposure estimates, fluoroscopic dose estimation system — continued

				Kilovolt peak 90		
					Exposure time in seconds	
Estimate method	Right ovary	Left ovary	Testes	Milliamperage	Postero-anterior	Left-lateral
	(Milliroentgens)					
Gastrointestinal Series						
Dosimetry	45	30	19	2.0	221	0
System	44	33	1.8			
Ratio	0.98	1.10	0.09			
Dosimetry	24	16	24	2.0	0	91
System	15	11	0.6			
Ratio	0.63	0.69	0.03			
Dosimetry	24	25	12	2.0	85	0
System	18.5	16	1.1			
Ratio	0.77	0.64	0.09			
Dosimetry	13	30	12	2.0	0	113
System	18.5	19	1.4			
Ratio	1.42	0.63	0.12			

[a] The ratio is the estimated exposure (E_m) expressed as a proportion of the measured exposure (E_d).

estimates, since two-thirds of the 27 paired exposures differed by 4 percent or less and only 5 had a deviation greater than ± 15 percent. These data indicate good reproducibility by the dose model in the exposure range of 10 mR to 4000 mR.

Given that the reproducibility of the dose model was acceptable, the other logical sources for the observed differences between measured and estimated exposure were the direct dosimetry and/or the alignment of film exposure data with the exposure ratio grid system. Two conclusions were derived from an analysis of the data in table 1:

1. As the level of gonadal exposure rises, there is an increased probability of direct beam irradiation. For example, an exposure of 1000 mR to an ovarian site from scattered radiation at average exposure parameters would require that the edge of the beam be within 3 to 6 centimeters of the site for an exposure time of approximately 2-1/2 minutes. However, 20 to 30 seconds of direct beam exposure to the site could produce this same exposure value without a contribution from scattered radiation for the remaining portion of the time. Thus, the model estimates (E_m) and dosimetry measurements (E_d) greater than 100 mR probably resulted from a close proximity of the beam to the gonadal site.

2. The converse is true for low exposure estimates. For example, an exposure of 50 mR at the ovarian site, under average examination conditions, would require that the beam always be distant from the site and never within 3 to 6 centimeters. Less than one second of direct irradiation at the gonadal site would produce an exposure of this magnitude with no contribution from scatter for the balance of the examination. Therefore, the model estimates (E_m) and dosimetry measurements (E_d) less than 100 mR probably resulted entirely from scattered radiation to the gonadal site with no probability of a contribution from direct beam irradiation.

It is apparent, therefore, that errors in alignment of film exposure data with the exposure ratio grid system would produce considerable variability between the measured and estimated gonadal exposure for any individual examination. This factor however, fails to explain the clustering of the ratio values described above; therefore, the exposure ratio grid system must be considered as a contributor to the apparent overestimation of the high exposure estimates and to the underestimation of the low exposure estimates. A sample table from the exposure ratio grid system is shown in exhibit 22. For operational convenience, the exposure ratio value of any cell less than 0.0001 was considered to be zero.

Since high exposure estimates appear to result from close proximity of the beam to the gonadal site, the ratios for grid cells near the ovarian sites might be somewhat high. These exposure ratios would have the greatest influence on the accumulated gonad doses when exposure is centered near the gonadal site. Such values are difficult to obtain with good accuracy. However, when the mean of the E_m/E_d ratio for exposures greater than 100 mR is corrected for film absorption and backscatter, it is within the limits of error expected for the dose model.

Averaging all 50 ovarian test determinations, the mean value of the E_m/E_d ratio is 1.43; the ratio corrected for backscatter and film absorption is 0.93. Thus, the ratio of E_m/E_d for ovarian exposures over all examinations would approximate 1.0.

With regard to the testicular exposure estimates, it is apparent that almost all testicular exposure resulted from scattered radiation with very little chance of a contribution from direct beam radiation. The mean ratio for testicular exposures greater than 20 mR is 1.56 ± 9 percent. When corrected for backscatter and film absorption a mean ratio of 1.03 is obtained.

For testicular exposures less than 20 mR, the operational cutoff in the exposure ratio grid system appears to have been significant because small differences in the level of testicular exposure are reflected as relatively large proportional errors. This effect results from the size of the base on which the proportional difference is determined. When the mean value of the E_m/E_d ratio for testicular exposures less than 20 mR was corrected for backscatter and film absorption, the result is a mean of 0.24. Although the testicular exposure estimates in the range of 0-20 mR might have been corrected, the effect of such a correction on average testicular exposure and dose estimates would have been minimal.

Chapter 4

PRINCIPAL ESTIMATES OF POPULATION EXPOSURE

Chapter 4

PRINCIPAL ESTIMATES OF POPULATION EXPOSURE

The previous two chapters presented the methodology for estimating the gonad dose from each radiographic and fluoroscopic examination in the Study. Estimation of population dose, including average gonad doses for specific population groups or examination types and estimates of genetically significant dose, also require data on the distribution of X-ray examinations by selected demographic and examination characteristics. This chapter summarizes findings from the earlier report, "Population Exposure to X-rays, U.S. 1964" (*21*).

NUMBER OF PERSONS X-RAYED AND VOLUME OF X-RAY VISITS

During 1964, approximately 108 million persons (58 percent of the estimated 187 million persons in the civilian noninstitutional population of the United States) had one or more medical or dental X-ray visits. The total number of X-ray visits included 93 million for medical and 50 million for dental. The number of medical X-ray visits estimated for 1964 was 8 percent greater than the 85 million estimated for 1961. The annual rate of visits per 100 population rose from 47.9 visits in 1961 to 49.8 visits in 1964. The increase occurred principally among children under 15 years of age and among older adults (fig. 1). The rise in medical X-ray visit rates between the two years is shown in figure 2 by primary area of the body examined.

The greatest increase involved visits for abdominal X-rays (most common among older persons). Analysis of medical visit rates by age and sex reveals the rates for males to be higher than those for females at most ages (fig. 3). The reversal occurring in the oldest age group is accounted for by the preponderance of abdominal X-ray visits for females at the older ages (fig. 4).

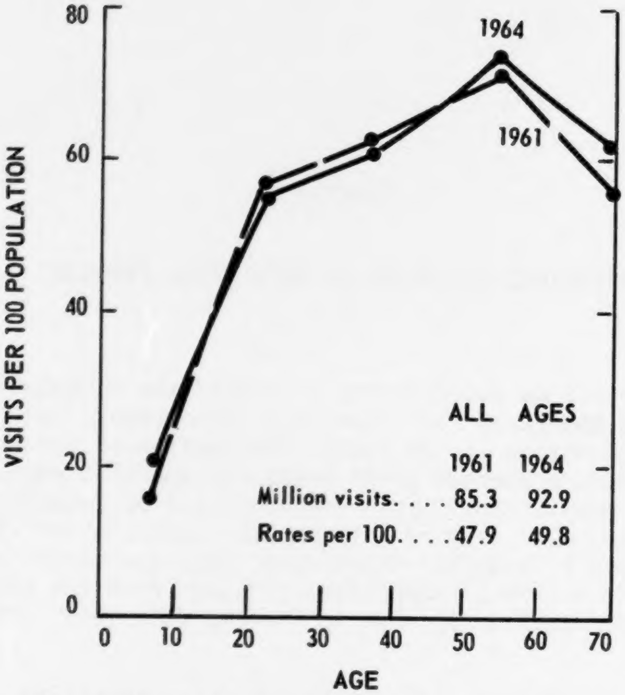

Figure 1. Estimated annual rate of medical X-ray visits by age, United States, 1961 and 1964.

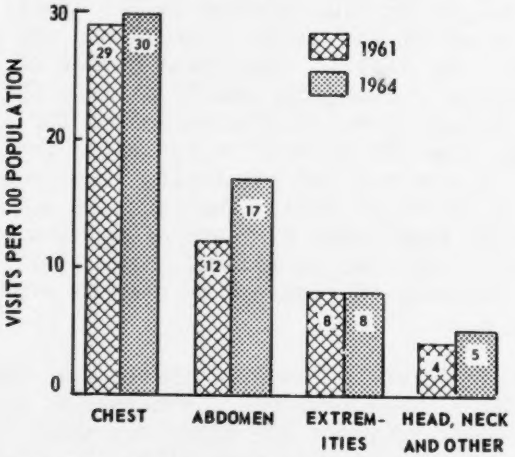

Figure 2. Estimated annual rate of medical X-ray visits by area of the body X-rayed, United States, 1961 and 1964.

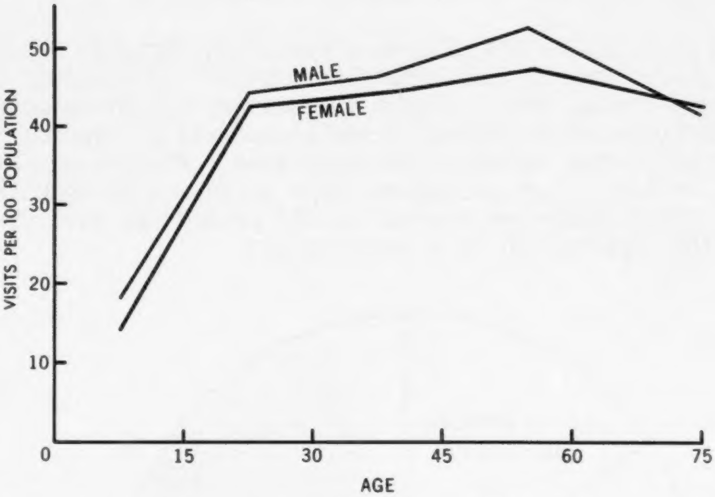

Figure 3. Estimated annual rate of medical X-ray visits by age and sex, United States, 1964.

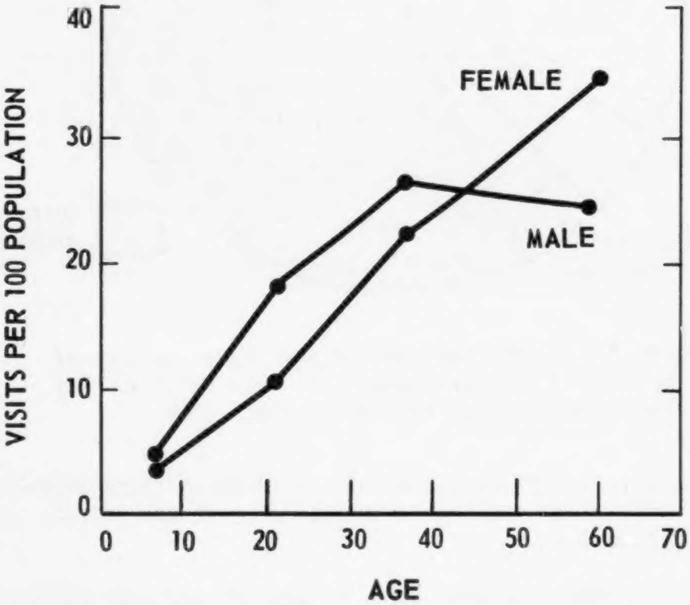

Figure 4. Estimated annual rate of abdominal X-ray visits by age and sex, United States, 1964.

VOLUME AND DISTRIBUTION OF MEDICAL EXAMINATIONS

Approximately 105 million medical radiographic X-ray examinations and 10.5 million fluoroscopic examinations were performed during 1964. Figure 5 shows the estimated percentage distribution of medical X-ray procedures by type of facility at which the procedure was performed. Fifty-eight percent of all medical X-ray procedures were performed in hospitals. An estimated sixty-one percent of all procedures were performed under the supervision of a radiologist.

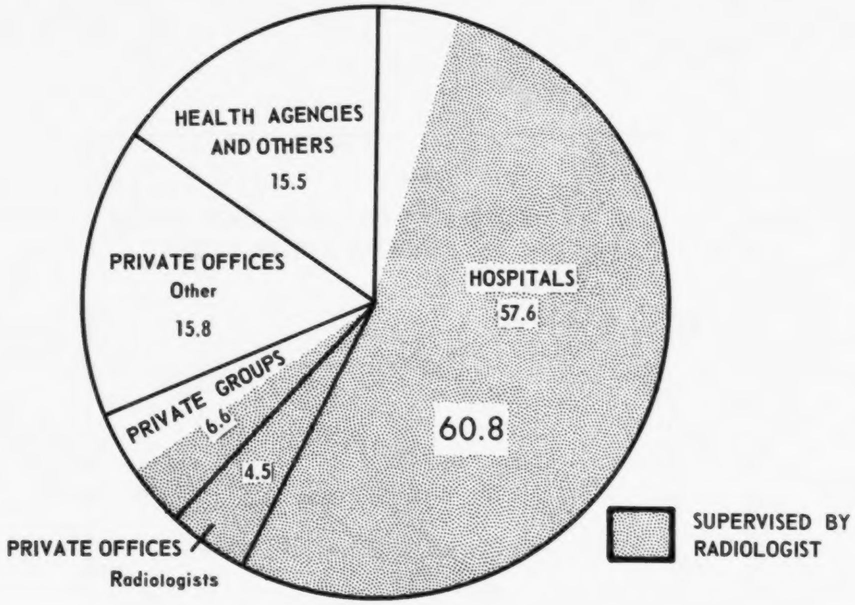

Figure 5. Estimated percentage distribution of medical X-ray procedures by type of facility and supervision, United States, 1964.

The percentage distribution of medical procedures done in private offices according to speciality of the practitioner is shown in figure 6.

The estimated annual rate by age of persons having medical procedures at selected types of facilities is shown in table 1.

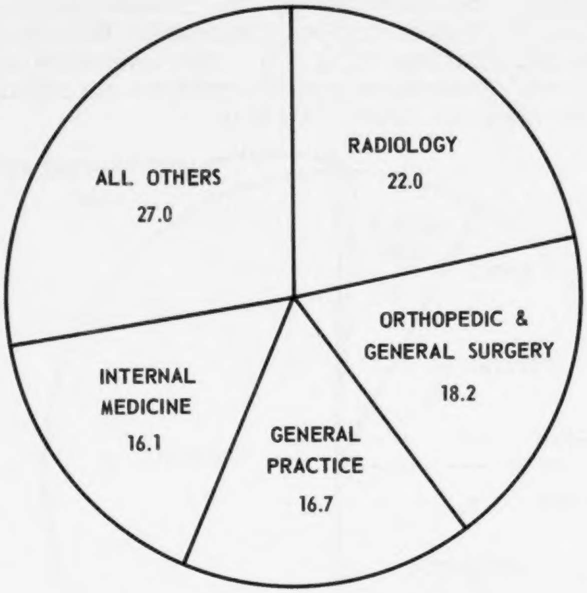

Figure 6. Estimated percentage distribution of medical X-ray procedures performed in private offices by specialty of practitioner, United States, 1964.

Table 1. Estimated annual rate of medical X-ray procedures by age of person and type of facility, United States, 1964

Age	All facilities	Hospitals	Private offices	Others
	Rate per 100 persons			
All ages	63.7	36.7	13.0	14.0
Under 15	25.9	17.5	(*)	(*)
15 – 29	65.0	33.8	11.8	19.4
30 – 44	77.2	42.3	14.6	20.3
45 and over	94.8	55.8	21.0	18.1
45 – 64	101.4	57.7	22.5	21.2
65 and over	80.4	51.6	(*)	(*)

Radiographic examinations of the thorax, including photofluorographic chest examinations, accounted for one-half of all radiographic examinations (fig. 7). The estimated annual rates of medical X-ray procedures per 100 persons according to age, sex, and body area are shown in table 2.

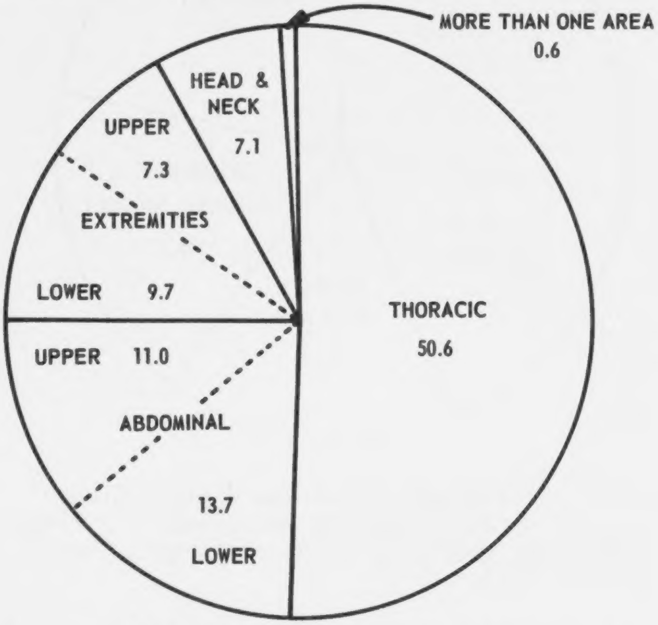

Figure 7. Estimated percentage distribution of radiographic examinations by body area, United States, 1964.

NUMBER OF FILMS

The estimated number of medical radiographic films taken in the United States during 1964 was 232 million, with an additional 48 million spot films taken during fluoroscopic examinations. An average of 2.2 films per radiographic examination (including photofluorographic chest films) were taken. Figure 8 shows the estimated percentage distribution of number of films per examination for selected body areas. Figure 9 shows the estimated mean number of films per radiographic examination at selected types of facilities.

Table 2. Estimated annual rate of medical X-ray procedures by body area, age, and sex, United States, 1964

Age and sex	All procedures	Body area			
		Thorax	Abdomen	Extremities	Head neck, and other
	Rate per 100 persons				
All persons	63.7	29.4	18.8	9.8	5.7
AGE					
Under 15	25.9	10.2	(*)	8.7	(*)
15 – 29	65.0	34.7	11.4	12.3	(*)
30 – 44	77.2	35.1	27.9	(*)	(*)
45 and over	94.8	42.6	34.1	10.4	7.8
45 – 64	101.4	46.4	34.3	11.3	9.3
65 and over	80.4	34.2	33.5	(*)	(*)
SEX					
Male	67.2	30.3	19.1	12.2	5.6
Female	60.4	28.4	18.5	7.6	5.8

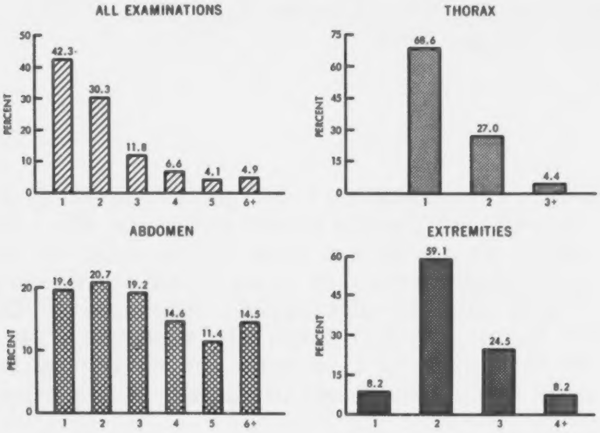

Figure 8. Estimated percentage distribution of radiographic examinations by number of films per examination for selected body areas, United States, 1964.

The greater average number of films per examination (fig. 9) in private offices of radiologists may reflect a higher proportion of more complicated procedures. Sixty percent of all abdominal examinations had three or more films (fig. 8); most of these examinations are performed by radiologists.

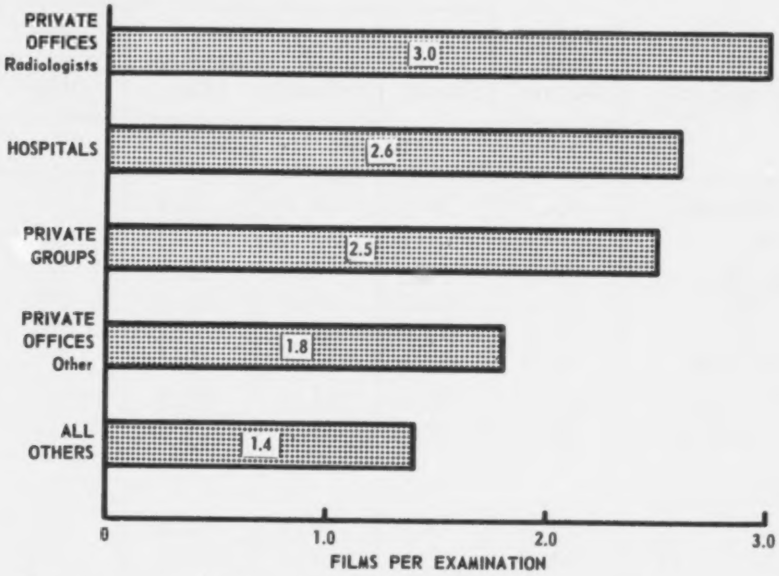

Figure 9. Estimated mean number of films per radiographic examination by type of facility, United States, 1964.

BEAM SIZE

An important determinant of the amount of X-ray exposure received by the patient during examinations is the size of the X-ray beam. Restriction of the beam to the size of the film provides an effective control of excess radiation exposure. More than one-half of all radiographic exposures in the Study had beam sizes at least 1-1/4 times the reported film area. Mean ratios of beam area to film area for radiographic films of selected body areas are shown in figure 10 according to type of facility.

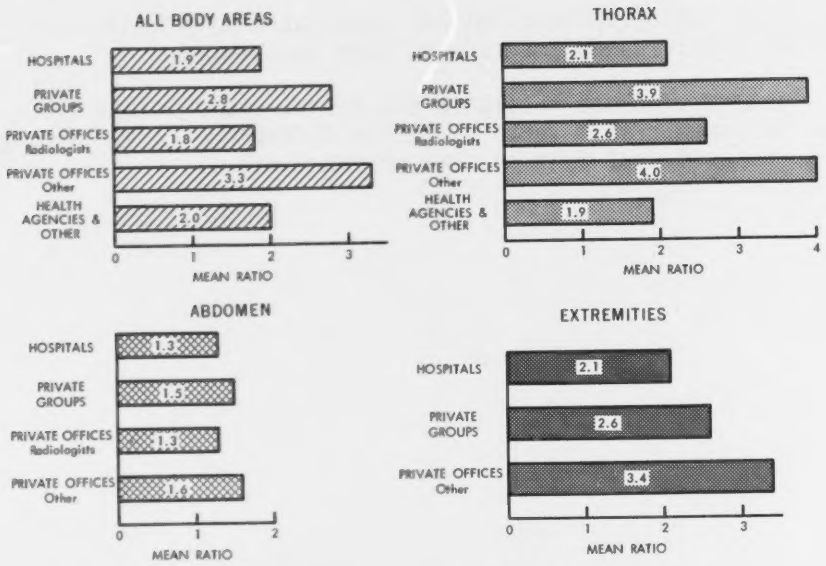

Figure 10. Estimated mean ratio of beam area to film area for radiographic films for selected body areas by type of facility, United States, 1964.

Although the mean ratio of beam area to film area for films taken at health agencies was relatively small (2.0), these are primarily photofluorographic examinations of the thorax for which the beam area was usually fixed. There was very little difference among facilities in these mean ratios for abdominal examinations. The largest mean ratios were associated with radiographic films of the thorax. Although misalignment contributes to excess beam area, data from the film pack procedure indicate that this was not an important contributing factor to the large beam areas found in the Study.

ESTIMATES OF EXPOSURE

Estimates of exposure in milliroentgens at the skin entrance were obtained for each film reported in the Study. These estimates are shown in exhibit 14 to the nearest milliroentgen, although this precision should not be associated with these averages. As one might expect, higher exposure values for radiographic films are associated with those examinations requiring delineation of bony structures.

Similar exposure estimates for dental examinations are given in exhibit 15. There is little difference in the average exposure per dental film by type of examination.

Chapter 5

ESTIMATES OF GONAD DOSE

Chapter 5

ESTIMATES OF GONAD DOSE

Gonad dose is a measure of the radiant energy that is absorbed by the ovaries or testes from a source of ionizing radiation. Estimates presented here of gonad dose from roentgenologic examinations are based on data from the 1964 X-ray Exposure Study and on the experimental models described in Chapters 2 and 3.

The gonad dose from a particular X-ray examination depends primarily on tube current, duration of exposure, beam quality, distance between patient and source of X-rays, and the number of films taken. The most important factor in determining gonad dose, however, is the location of the direct beam relative to the gonads. The gonad dose will be reduced by a factor of from 50 to 200 if the gonads lie even slightly outside the direct beam. Since radiation is absorbed by tissue overlying the gonads, similar skin exposures produce ovarian doses significantly lower than corresponding testicular doses.

GONAD DOSES BY AGE

Mean gonad doses from examinations of children were generally significantly lower than those for adults (table 1). The sharp differential in the mean dose per examination of children for all body areas results in part from the lower average doses for abdominal examinations of children and in part from the proportionally higher concentration of examinations of the skull and extremities in the pediatric age group.

GONAD DOSES BY TYPE OF FACILITY

Table 2 presents estimates of mean gonad doses per film by body area and type of facility at which the X-ray examin-

Table 1. Estimated mean gonad doses from radiographic examinations by age, sex, and body area, United States, 1964

Body area and sex	All ages[a]	Under 15	15-29	30-44	45 and over[a]
	Millirads per examination				
Male					
All body areas	239	35	262	340	255
Head and neck	3	-	(*)	(*)	17
Thorax	8	2	24	2	4
Abdomen	1,071	222	1,808	1,340	837
Extremities	57	9	79	11	159
Female					
All body areas	70	16	54	106	101
Head and neck	3	(*)	(*)	9	(*)
Thorax	7	12	4	10	6
Abdomen	351	138	370	352	422
Extremities	-	1	-	-	(*)

[a] Restricted to females under 50 years of age and males under 60.

ation was performed. While doses for thoracic films varied little among the types of facilities, the data suggest that those done in private offices of radiologists may be somewhat lower in mean gonad dose than those done elsewhere. Ovarian doses from abdominal films varied little by type of facility. Testicular dose levels from abdominal films are higher in private offices of nonradiologists than in other facilities. Mean gonad doses for films of the head and neck and of the extremities are also presented, although a comparison by facility type is precluded because of the variability of the dose estimation procedure at low levels.

Table 2. Estimated mean gonad doses per radiographic film by sex, body area, and type of facility, United States, 1964

Sex and body area	All facilities	Hospitals	Private office radiologists	Other private offices	All others
	Millirads per film				
Male					
Head and neck	-	1	-	-	(*)
Thorax	6	8	4	6	1
Abdomen	273	258	281	343	7
Extremities	23	35	-	2	-
Female					
Head and neck	1	1	-	-	-
Thorax	5	4	1	3	8
Abdomen	100	103	71	98	(*)
Extremities	-	-	-	-	-

GONAD DOSES BY TYPE OF EXAMINATION

Mean gonad doses for selected types of roentgenologic examinations are shown in appendix table 1. Since the variability inherent in the observed sample dose values has a significant impact upon the mean values, estimates of the median and of the quartile distribution of gonad dose for each examination type have also been calculated and are shown in appendix table 2.

Examinations of the Head and Neck: Gonad doses from examinations of the head and neck were generally low. More than 90 percent of these examinations yielded estimated ovarian or testicular doses of less than 1 millirad.

Examinations of the Chest: Photofluorographic (PFG) examinations represented approximately one-third of all examinations of the chest. Testicular doses from more than 90 percent of all PFG examinations were less than one millirad and were in no case found to be in excess of 10 millirads. Ovarian doses from these examinations were generally higher than testicular doses. Three-fourths of the examinations resulted in ovarian doses of 12 millirads or less; however, a few examinations yielded ovarian doses of nearly 200 millirads. It is probable that these examinations represent inclusion of the ovaries in the direct beam.

Testicular doses from radiographic chest examinations were relatively low; however, a small number of examinations were found with testicular doses up to 10 millirads. These dose levels presumably resulted from poor techniques, in particular from failure to collimate the X-ray beam. Although the number of sample examinations resulting in substantial gonad doses was small, the data suggest that persons of short stature may be more likely to receive large gonad doses from chest radiographs. For such persons, poor collimation is more likely to result in direct beam irradiation of the gonads.

Examinations of the Thoracic Spine and Shoulder: The mean testicular dose of 184 millirads from thoracic spine examinations (appendix table 1) reflects the inclusion of a single large outlying value which appeared not to represent an error in dosimetry or data processing. The mean testicular dose excluding this case was 3 millirads. The quartile data indicate that 75 percent of these examinations yielded a testicular dose of 5 millirads or less. Ovarian doses from these examinations were also low.

X-ray examinations of the shoulder produced gonad doses of less than one millirad in more than 90 percent of the cases and less than 10 millirads in all cases.

Upper Gastrointestional Series Examinations: Most upper gastrointestional series examinations reported in the survey included both radiographic films and fluoroscopic procedures. These were treated separately for the purposes of this Study. As a result, the number of such procedures is almost twice the number of patients who had this diagnostic work done. Both testicular and ovarian doses were higher for the radiographic than for the fluoroscopic upper gastrointestinal series. This is primarily due to the use of small beam sizes in fluoroscopy. Radiographic ovarian doses, with a median of about 300 millirads, were generally considerably higher than the corresponding male doses with a median of 6 millirads.

Barium Enema Examinations: As with the upper gastrointestinal series, a barium enema typically included both a radiographic and a fluoroscopic portion. For study purposes, these were also treated as separate examinations. Radiographic films of barium enemas produced high average ovarian and testicular doses. For males, the average gonad dose was over 30 times as large for the radiographic as for the fluoroscopic portion of the barium enema. Ovarian doses were also higher for the radiographic procedure. Much of this difference may be attributed to the use of restricted field sizes in fluoroscopy.

Examinations of the Gall Bladder: Gonad doses for these examinations were quite low for males (virtually all less than 5 millirads); however, for females, the doses ranged to more than one rad, with a median of about 120 millirads.

Intravenous or Retrograde Pyelographic Examinations: Gonad doses from these examinations were among the higher doses for both males and females. The doses were fairly uniformly distributed throughout their respective ranges for both sexes. The range for ovarian doses was from about 100 millirads to 1 rad. For males, the range was much greater, from less than 10 millirads to more than 13 rads. Intravenous and retrograde pyelograms have a significant impact on the mean gonad dose calculated for all body areas for persons of both sexes, since they are among the more commonly performed procedures yielding high gonad doses.

Examinations of the Abdomen: This category includes general abdominal studies, noncontrast studies of the kidneys and bladder, fetograms, and pregnancy studies. Although the mean gonad doses were about the same for males and females, the median testicular dose was about 20 millirads, while the corresponding median ovarian dose was about 300 millirads.

Examinations of the Lumbar and Lumbo-sacral Spine: Lumbar and lumbo-sacral spine examinations produced the highest mean testicular doses of any examinations; ovarian doses resulting from this procedure were also high. For these examinations, testicular doses had a very wide range with 25 percent less than 10 millirads while the highest 25 percent were greater than 5 rads. This range results, in part, from differences in the number of films per examination, in patient positioning, and the extent to which the beam is collimated.

Examinations of the Pelvis and Lumbo-pelvis: Pelvic examinations were relatively infrequently reported for women in the survey sample and resulted in fairly small ovarian doses. For males, however, these examinations were much more frequent and involved greater gonad doses. One-half of the testicular doses were greater than 500 millirads and one-fourth were greater than one rad.

Examinations of the Hip: Testicular doses from hip examinations varied from 2 millirads to 4 rads. Some of the variation may result from patient positioning and the extent of collimation. The sample number of examinations of females was not large enough to permit the calculation of a reliable mean ovarian dose.

Examinations of the Extremities: Examinations of the upper extremities produced low gonad doses (in most cases less than one millirad). For females, examinations of lower extremities also produced low gonad doses. Testicular doses from examinations of the lower extremities were small except for examinations of the femur. Twenty-five percent of these examinations involved testicular doses of from 900 millirads to over 3 rads.

ACCUMULATED GONAD DOSES FOR SELECTED YEARS OF LIFE

The 15-, 30-, and 45-year-accumulated gonad doses from medical X-ray examinations are shown in figure 1 and table 3. If the examination and dose rates in 1964 were to remain constant for 30 years, a male child born in 1964 would receive on the average a mean gonad dose of 560 millirads from medical X-rays during the first 30 years of his life. The corresponding figure for females would be 110 millirads. The 15-year-accumulated gonad doses were only 30 and 10 millirads for males and females, respectively. The 45-year doses, encompassing almost all of the procreative period, would be 1340 millirads for males and 300 millirads for females.

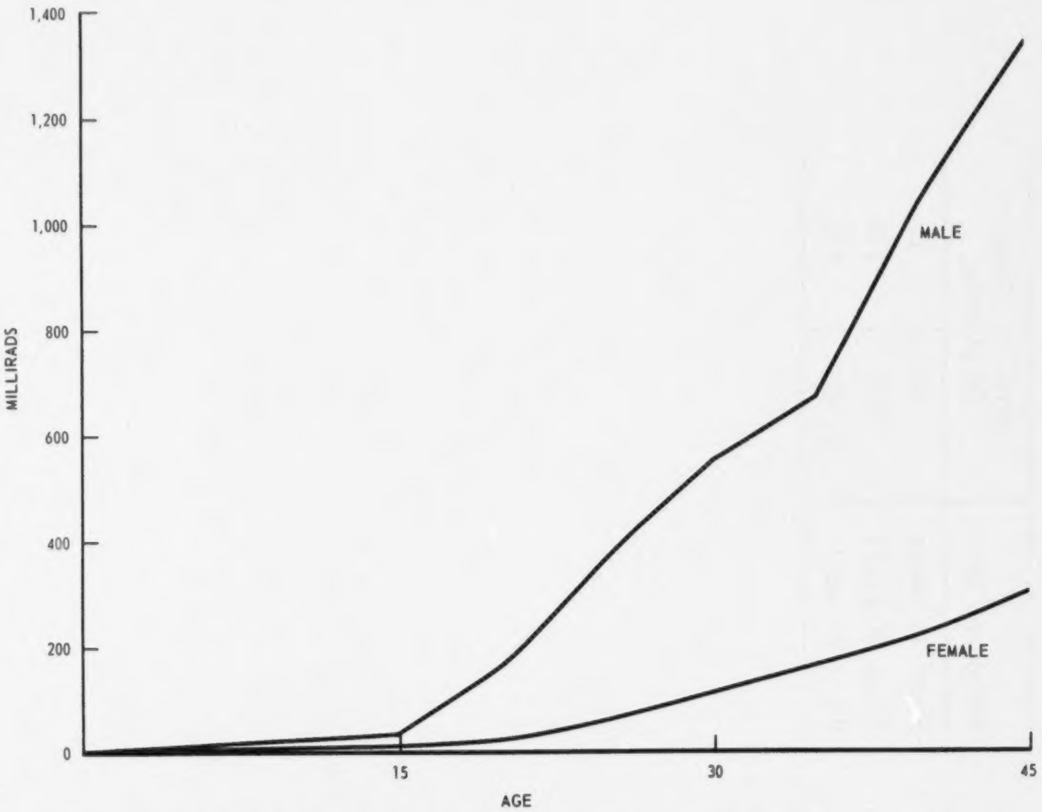

Figure 1. Estimated accumulated mean gonad doses from diagnostic medical roentgenology by age and sex, United States, 1964.

Table 3. Estimated accumulated mean gonad doses from diagnostic medical roentgenology by sex and period of life, United States, 1964

Period of life	Male (Millirads)	Female
First 15 years	30	10
First 30 years	560	110
First 45 years	1,340	300

Chapter 6

ESTIMATES OF GENETICALLY SIGNIFICANT DOSE

Chapter 6

ESTIMATES OF GENETICALLY SIGNIFICANT DOSE

METHOD OF CALCULATION

The genetically significant dose (GSD) is defined as the gonad dose which, if received by every member of the population, would be expected to produce the same total genetic effect on the population as the sum of the individual doses actually received (28).

In the mathematical formula for GSD, the implicit assumption is made that the genetic effect resulting from an X-ray examination may be indexed by the product of the gonad dose received by the person examined and his expected future number of children. The sum of such products over all the individuals in a population who receive X-ray examinations would then equal an index of the total genetic effect to the population.

If the expected future number of children is assumed to be the same for all individuals of the same age and sex, individuals can be grouped and average doses for each age – sex class can be calculated, rather than using the actual individual doses received. Thus the GSD can be expressed algebraically as:

$$\text{GSD} = \frac{\sum D_i \hat{N}_i P_i}{\sum N_i P_i}$$

Where,

D_i = the average gonad dose to persons age *i* who receive X-ray examinations,

$\hat{N}_i$ = the number of persons in the population of age *i* who receive X-ray examinations,

P_i = the expected future number of children for a person of age i, and

N_i = the number of persons in the population of age i.

This general formula is consistent with the formula described by the United Nations Scientific Committee on the Effects of Atomic Radiation (28). In order to minimize variability due to sampling, population age groups were formed using fifteen year intervals. Data were also categorized by sex, including a fetal classification, since the expected future number of children and the average gonad doses received at each age differ substantially for the sexes and the fetal population. Similarly, the X-ray examinations were grouped by types of examinations of the same general description. The final formula used for the computation of GSD was:

$$\mathrm{GSD} = \frac{\sum_i \sum_j \left[\left(\frac{\text{male}}{\hat{N}_{ij} P_i D_{ij}} \right) + \left(\frac{\text{female}}{\hat{N}_{ij} P_i D_{ij}} \right) + \left(\frac{\text{fetus}}{\hat{N}_{ij} P_i D_{ij}} \right) \right]}{\sum_i \left[\left(\frac{\text{male}}{N_i P_i} \right) + \left(\frac{\text{female}}{N_i P_i} \right) + \left(\frac{\text{fetus}}{N_i P_i} \right) \right]}$$

where,

i indexes age group and

j indexes type of examination performed.

The N_{ij} terms in the formula represent the annual number of examinations of type j received by individuals in age group i. These numbers were derived from data generated by the Public Health Service X-ray Exposure Study of 1964 (21). Data on the numbers and types of examinations performed on pregnant women who bear live children were derived from a study of X-ray experience of women during pregnancy (29). The age – sex distribution of medical examinations is shown in appendix table 3.

The expected future number of children of an individual in a specified age – sex group was derived from 1964 birth rates and survival data published by the National Center for Health Statistics (30). The calculation of expected future children is based on an assumption that the average individual will have a future child expectancy based on the observed specific birth rates for 1964. No use of fertility projections was made. The total expected future number of children of an individual in any particular age – sex group can then be derived by summing the products of the birth rate at each successive age and the probability of surviving to that age. The numbers thus derived are shown in appendix table 4.

Although it is recognized that there may be significant differentials in future fertility between persons undergoing selected types of roentgenologic examinations and other persons in the general population, a lack of specific data on this subject precluded the adjustment of the expected future numbers of children for such persons. Thus, the same values of expected future children were used for each examination classification as well as for the calculation of the denominator of the GSD formula. The expected number of children shown for the fetus was determined by combining the age – zero values for males and females in a 105:100 proportion. This ratio is approximately the sex ratio of live births.

The mean gonad dose was calculated for each age – sex – examination class. Average gonad doses to the fetus were derived by assuming that the fetal dose for a specific type of examination is the average gonad dose received by all women ages 15 to 44 who underwent the examination. The dose for any particular class reflects variations by type of facility where the examinations were performed, geographic area, characteristics of persons examined, and variations in other factors related to dose. The gonad doses which were used in the GSD calculation are shown in appendix table 1.

TOTAL GENETICALLY SIGNIFICANT DOSE

The GSD for the United States for 1964 was estimated to be 55 millirads per person, per year. This estimate ranks the United States higher than other countries in which studies have been done, as shown in appendix table 5 (*31*). The estimates range from a low of 12 millirads per person, per year for New Zealand to a high of 55 for the United States. Since some of these studies were completed more than 10 years ago, differences in GSD may reflect, among other things, changes in roentgenologic practice over time.

One obvious difference contributing to the level of GSD is the examination rate for each country. Appendix table 5 shows the ratios of GSD to the examination rate for each study. This ratio represents a normalization of GSD with respect to examination rates while retaining the effects of dose levels and population parameters upon the genetically significant dose. Using this index, the United States estimate is found to be closer to values for other countries in which examination rates are significantly different from those for the United States.

Table 1 summarizes the proportional contribution to the GSD resulting from conventional radiography, fluoroscopy, and photofluorography. Although photofluorography accounts for 14 percent of all medical X-ray examinations, these procedures contribute less than 1 percent to the total genetically significant dose.

Table 1. Estimated percentage distribution of genetically significant dose from diagnostic medical roentgenology, United States, 1964

Type of procedure	Percent
All types	100
Radiography	96
Fluoroscopy	4
Photofluorography	-

GSD BY AGE AND SEX

Figure 1 summarizes the percentage contribution to the GSD by sex and age group. It is apparent that males 15 to 29 years of age are the largest single contributors to the GSD, accounting for 61 percent of the total. Over 80 percent of the total GSD resulted from examinations of males; a small proportion was produced by fetal exposure due to examinations performed on pregnant women.

The percentage contribution to GSD for five countries is shown in table 2. The findings for the United States are significantly different from the foreign studies.

The relative proportion of the GSD contributed by a given age — sex group is proportional to the number of examinations, average number of expected future children, and the total gonad dose experienced by that group. By considering the ratio of GSD per examination contributed by an age group relative to the corresponding figure for all ages, the effect of number of examinations is removed. This index is shown in column 5 of appendix table 6. If there were no difference by age in the average gonad dose, then this index would be proportional

Table 2. Estimated percentage distribution of genetically significant dose by sex (selected studies)

Sex	United States	Sweden	United Kingdom	New Zealand	Denmark
	Percent				
Total	100	100	100	100	100
Male	82	52	36	47	40
Female	16	26	38	37	31
Fetus	2	23	26	16	29

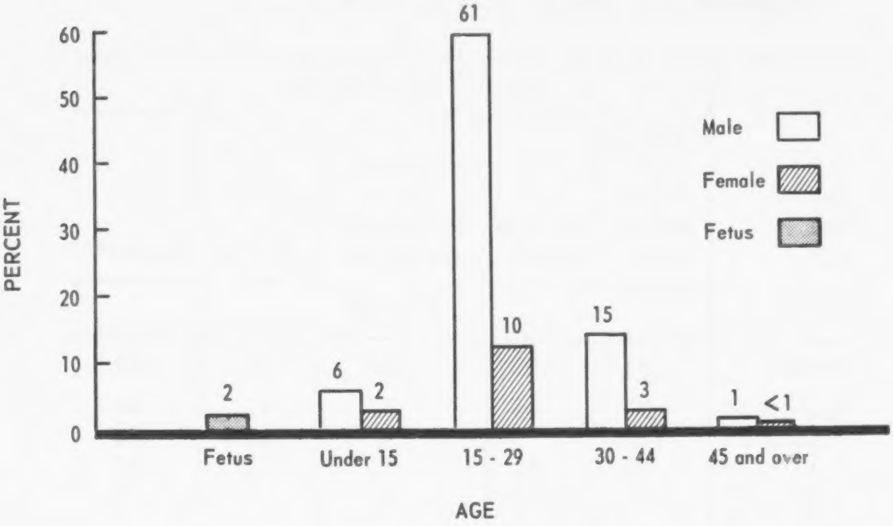

Figure 1. Estimated percentage distribution of genetically significant dose from diagnostic medical roentgenology by age and sex, United States, 1964

to the expected future children by age (column 6). The data in appendix table 6 indicate that, for ages 15 and over, this index follows the pattern of child expectancy. For the fetal group and for ages under 15, the index value is significantly lower than the number of expected future children, due to the relatively low frequency of high-dose examinations, resulting in lower gonad doses for pregnant women and young children.

GSD BY TYPE OF EXAMINATION

Appendix tables 7, 8, and 9 show the contribution to GSD for each examination type by age — sex groups. A few high-dose examinations, such as lumbar and lumbo-sacral spine, barium enema, intravenous or retrograde pyelogram, pelvic, and abdominal examinations are the principal contributors to GSD. Table 3 indicates the percentage contribution to GSD for these exam-

Table 3. Estimated percentage distribution by age and sex of genetically significant dose from selected examinations, United States, 1964

Sex and age	Type of examination				
	Lumbar and lumbo-sacral spine	Barium enema	Intravenous or retrograde pyelogram	Pelvis	Abdomen
	Percent				
Total	100	100	100	100	100
Male	97	69	77	95	66
Under 15	(*)	3	10	13	26
15 - 29	75	51	42	75	37
30 - 44	22	14	19	7	3
45 - 59	-	1	6	-	-
Female	3	31	21	-	14
Under 15	(*)	7	3	-	-
15 - 29	2	22	16	(*)	7
30 - 44	-	2	2	-	7
45 - 49	-	-	-	(*)	-
Fetus	-	-	2	5	20

ination types by age-sex group. The percentage distribution of GSD by contributing examination type is also shown in figure 2. Similar data for males 15 to 29 years of age is shown in figure 3.

The finding that a high percentage of the GSD is contributed by a relatively small number of types of procedures is not unique to this study. Appendix table 10 presents percentage and cumulative percentage distributions of GSD by examination types, for this and for selected other studies. Between 64 and 89 percent of the GSD in each instance is contributed by the same five examination types which accounted for over 80 percent of the genetically significant dose in the United States. Although these examinations types are identified as high contributors to the GSD, they are not necessarily the five highest for all countries. The lumbar and lumbo-sacral spine examination is, however, the largest single source of GSD in all studies except Denmark, where the intravenous or retrograde pyelogram contributes 14.9 percent of the GSD.

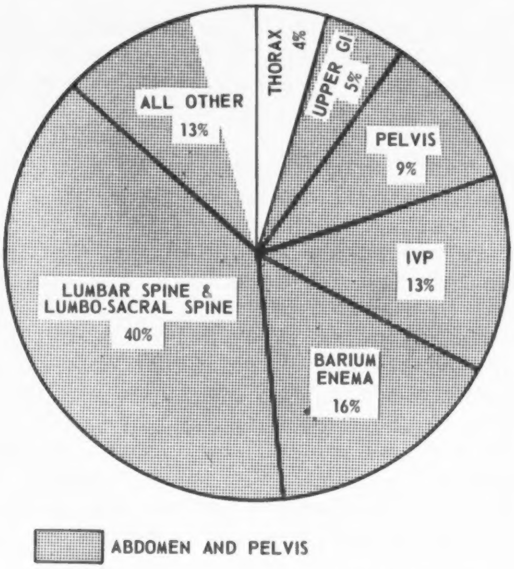

Figure 2. Estimated percentage distribution of genetically significant dose by type of medical roentgenologic examination, United States, 1964

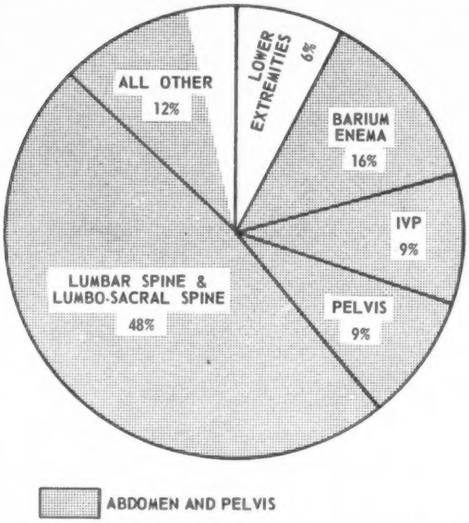

Figure 3. Estimated percentage distribution of genetically significant dose by type of medical roentgenological examination for males 15 to 29 years of age, United States, 1964

Chapter 7

DISCUSSION AND SUMMARY

Chapter 7

DISCUSSION AND SUMMARY

METHODOLOGY

The present study differs in several respects from those which have been conducted in other countries and in local areas within the United States. The major differences are:

1. the estimation of X-ray visit and examination experience of the population based on personal interview with household respondents;

2. the collection of exposure data by means of a follow-up mail survey to X-ray facilities named in the interview;

3. the independent estimation of exposure based on film-pack findings; and

4. the estimation of dose based on laboratory-developed models used in conjunction with reported exposure parameters and film-pack findings.

This study utilized a multistage probability sample of the civilian noninstitutional population of the nation, rather than a national sample of radiologic facilities or a sample of facilities in a geographic subarea; thus, the findings from this population-based study relate directly to the experience of the total population, without the need for special assumptions regarding the representativeness of the study group for making national estimates.

The use of "indirect dosimetry" had three advantages:

1. The collection of exposure data by mail survey and film-pack techniques did not require the presence of an outside observer during the conduct of actual examinations. Although some practitioners may have been influenced by the use of the film pack to record exposure, the influence of an out-

side observer probably would have had a greater impact than the technique used. The procedure followed in this study probably yielded data more representative of the usual practice of diagnostic roentgenology than that collected in other studies.

2. The indirect method permitted a detailed analysis of the factors which contribute to population dose. The availability of dose parameters for each examination made possible computer simulation of dose estimates under varying or hypothetical conditions. By this means, it was possible to estimate the impact of changes in radiologic technique and practice.

3. A more diverse group of persons, examinations, and radiologic facilities was included in the Study than would have been possible using direct dosimetry, and reflects more accurately the variations in practice as they exist in the Nation.

A disadvantage of the indirect dosimetric approach is the possible introduction of non-random error at any of the stages of the complex procedures. Procedures were instituted to assess the possible impact of such errors. The results of these procedures, in which direct dosimetry was compared with computer-estimated dose values, indicated acceptable levels of agreement. Dose estimates for those examinations which contributed most heavily to the genetically significant dose tended to have the smallest percentage errors, since most of these examinations involve direct beam irradiation of the gonads.

Estimates of the standard errors associated with population and examination characteristics were presented in an earlier report (21). To the extent that these extimates of GSD are dependent upon the distributions derived from the population survey, the sampling errors associated with population-based characteristics may be considered as also applicable to the estimates of GSD.

GONAD DOSE ESTIMATES

Medical Radiography

Medical radiographic examinations account for most of the genetically significant dose from diagnostic X-rays and are responsible for virtually all of the excess dose. Evidence that this excess results primarily from failure to restrict the primary beam to the area of interest, and in any case, to the area of the receptor film, is found in figure 10, Chapter

4. While these ratios of beam area to film area are relatively small for examinations of the abdomen, they are markedly larger for examinations of the thorax, (up to four times the film area).

Since any portion of an X-ray beam greater than the area of the film is unnecessary, it is apparent that the effective beam size cannot be greater than the film size in the plane of the film. It was possible, because of the design of the Study, to simulate estimates of gonad dose using effective beam sizes; that is, reducing all beam sizes to the reported film size. Estimates of gonad doses under such an assumption for selected types of examinations are shown in appendix table 11. The reductions resulting from the hypothetical restriction of beam size were most marked for mean testicular doses. Decreases ranged from less than 10 percent for examinations of the extremities to about 98 percent for the lumbar spine. Greatest reductions were noted for examinations of the abdomen and pelvis where restriction of beam size has the effect of excluding the testes from the useful beam. Reductions in ovarian doses were more modest, reflecting the more frequent unavoidable inclusion of the ovaries in the useful beam.

Evidence that adequate collimation can be achieved is also seen in figure 10, Chapter 4, where significant differences in the mean ratios of beam size to film size are found at different types of facilities. In general, the smallest ratios of beam area to film area were found in hospitals; this may reflect a greater concern and attention to the need for close collimation and the availability of specialized equipment. Examinations done in the private offices of physicians other than radiologists tended to show the largest ratios, possibly reflecting use of equipment on which provisions for collimation have not been provided or used, and a somewhat lower level of training and experience on the part of the technologist or other operator of the X-ray machine.

Dental Radiography

Data on dental exposures indicate that dental radiography is not a factor in excess gonad dose. An analysis of the film packs returned by dental facilities revealed that almost 80 percent of all dental examinations were done with a beam no larger than 3 inches in diameter. No dental film in the survey produced an estimated gonad dose higher than two-tenths of a millirad, with the mean gonad dose from all dental films less than one-tenth of a millirad.

Fluoroscopy

Past studies have indicated that fluoroscopic examinations produced relatively high exposures to patients. Data from this study did not support this finding with respect to gonad dose. As shown in appendix table 1, estimated mean gonad doses for fluoroscopic examinations of the gastrointestinal tract are low in comparison with the doses for radiographic films taken in conjunction with these examinations. The differential is particularly marked for testicular doses. Since the area of diagnostic interest is identical for the fluoroscopic and radiographic portions of the examination, this finding suggests that one of the major factors resulting in the low estimated fluoroscopic gonad doses is the complete exclusion of the testes from the direct beam and the partial exclusion of the ovaries, due to the small field sizes typically used in fluoroscopy. Other factors which affect the dose levels from fluoroscopic procedures include improvements in the design of fluoroscopic equipment (in particular, the use of image intensification systems) and the less frequent use of fluoroscopy by nonradiologists.

GENETICALLY SIGNIFICANT DOSE

Estimates of the genetically significant dose for selected countries are shown in appendix table 5. These estimates range from a low of 12 to a high of 55 millirads (the estimate for the United States). Differences in GSD among countries do not necessarily reflect a difference in average gonad dose per examination, since many other factors determine the level of genetic dose. The most important of these factors is the rate of persons examined per year; these data are also shown in appendix table 5. Examination rates varied from a low of 24 per 100 persons in Denmark, to a high of 53 per 100 in the United States (excluding mass screening procedures) based on the present study. Other factors which directly affect the level of genetically significant dose are differences in the types of examinations performed and the age distribution of persons examined by X-rays. Radiologic examinations of various types are not equally productive of gonad dose, and examinations of persons at ages over 35 contribute relatively little to the genetically significant dose. Additional factors to be considered in making international comparisons are the levels of fertility in each country and differences in medical practice, particularly in the usual number of films taken per specified examination.

The interpretation of comparative levels of genetically significant dose must also take into account the different methods used in various studies. Estimates of examination rates and distribution by population and examination characteristics were derived from a sample population survey for the United States; in other studies data were derived from routine service statistics. Average gonad dose values for the present study were obtained by means of film packs and mail survey report forms used as input to laboratory-developed dose models. Most of the other studies which have been done have utilized direct dosimetry, either on patients or phantoms, in a limited number of institutions and for a relatively restricted set of examination and patient characteristics.

One of the principal findings of this study in contrast to other studies relates to the proportional contributions to genetic dose from examinations of males, females, and from exposure of the fetus. In the United States, 82 percent of the estimated genetically significant dose was contributed by examinations of males, 16 percent by examinations of females, and only 2 percent by fetal exposure. Other studies have found that the male contribution to GSD ranged between 36 and 52 percent, with the female contribution between 26 and 38 percent, and fetal exposure accounting for 16 to 29 percent of the total GSD. The lower proportional contribution from examinations of males found in other studies may be due to differences in examination techniques, or may reflect the influence of an observer making dose measurements, resulting in unusual attention being paid to beam collimation and other dose-reduction procedures. In the present study, the use of film packs yielded estimates of beam sizes and exposure under usual operating conditions for over two thousand X-ray examinations.

The finding in the present study that fetal exposure resulted in a contribution of only 2 percent to the genetically significant dose reflects a lower rate of X-ray examinations performed on gravid women. This lower rate is in part a function of the years studied, since examination rates during pregnancy for the United States were based on 1963 data, whereas most of the other studies relate to earlier years. It is probable that an increasing awareness during recent years of the potential hazards of radiation to the developing fetus has influenced medical practice in the use of X-ray examinations on pregnant women.

The potential impact on average gonad doses of reducing all beam sizes to the film size has been discussed. Average gonad doses resulting from hypothetically reduced beam sizes are shown in appendix table 11. If these gonad doses are used in the calculation of genetically significant dose, a reduction from 55 millirads per person per year to 19 is obtained. The estimated average contribution to the genetically significant dose by sex and type of examination under the reduced beam size assumption is shown in appendix table 12. Estimates in this table may be compared with those in appendix table 7, which represent the comparable values based on the mean gonad doses found in the Study. The most marked reductions are found among examinations of the abdomen and pelvis. The contribution of the lumbar and lumbo-sacral spine, for example, is reduced from 22 millirads to 1.3 millirads with almost all of the reduction resulting from examinations of males. Whereas 80 percent of the 55 millirads per person per year is contributed by the examinations of males, the distribution by sex of the hypothetical 19 millirads per person per year is approximately even.

The reductions in genetically significant dose shown in appendix table 12 reflect only the impact of improved collimation and do not represent the maximum reductions possible through other improvements in radiographic technique.

SUMMARY

The X-ray Exposure Study conducted by the United States Public Health Service was designed to produce estimates of the X-ray exposure to the United States population. Estimates of the number of persons X-rayed, types of examinations, and exposure from these examinations were published in an earlier report, "Population Exposure to X-rays, U.S. 1964" (*21*). Estimates of gonad and genetically significant dose based on the data published in the earlier report are presented here. The following is a summary of highlights of this report.

A. Study design

The X-ray Exposure Study was conducted in several sequential stages (Chapter 1, figure 1):

1. a household interview survey of a representative sample of the U.S. population to obtain X-ray visit data;

2. a mail followup to the X-ray facilities where reported visits took place to obtain technical data and the exposure of film packs;

3. the merging and processing of the above sets of data to produce estimates of the X-ray experience of the U.S. population;

4. the development of dosimetric models for estimating gonad dose from the exposure data generated by the X-ray Exposure Study, and

5. the estimation of gonad doses and the genetically significant dose for the U.S. population based on the dosimetric models and the exposure data.

B. Dose estimation for radiographic examinations

1. The model for estimating the gonad dose received during radiographic examinations was developed at The Johns Hopkins University. Ratios of scattered radiation at selected surface sites, including gonadal locations, to direct beam irradiation at each of 3,000 locations in a 60-by 200-centimeter matrix corresponding to the X-ray tabletop, were developed. Tables of these scattered-to-direct ratios were produced for five separate projections and four half-value-layers, on 30 subjects selected to cover the wide range of heights and weights of persons included in the X-ray Exposure Study. Estimates of radiation dose to the gonads were then generated using these tables and the reported technical factors and beam size for each radiographic examination in the X-ray Exposure Study.

2. An evaluation procedure was carried out at the Hospital of the University of Pennsylvania. Thermoluminescent dosimetry was used to obtain direct measurements of exposure at the approximate external gonadal locations for a sample of 500 radiographic examinations. These measurements were then compared with calculated estimates of gonadal exposure derived from the dosimetric model for the same examinations. A comparison of mean differences indicated good agreement between the calculated estimates and the direct dosimetry.

C. Dose estimation for fluoroscopic examinations

The model for estimating gonad dose received during fluoroscopic examinations was developed at Emory University. A phantom was used to experimentally determine the percentage contribution to gonad exposure that results from a known exposure to a given surface unit area. A set of tables representing these percentage contributions was generated for postero-anterior and lateral positions, and for each of three half-value-layers. Estimates of radiation dose to the gonads were then derived from these tables and surface exposure extimates obtained from the fluoroscopic record film pack.

D. Estimates of gonad dose

Gonad doses from radiographic examinations ranged from less than 1 millirad to over 2 rads. Radiographic examinations of the abdomen and pelvis were found to produce the highest gonad doses, while examinations of the head, neck, and extremities produced low gonad doses. The maximum gonad dose from dental films was less than 1 millirad.

Testicular doses resulting from radiographic examinations of the abdomen and pelvis reflected the impact of beam sizes significantly larger than the minimum size needed to expose the film. A simulated restriction of beam size to the size of the film resulted in a marked reduction of testicular doses.

Ovarian doses from fluoroscopic examinations were found to be significantly higher than testicular doses from the same types of examinations. This finding reflects the fact that field sizes used in fluoroscopy usually excluded the testes but not the ovaries from the direct beam.

E. Genetically significant dose

The genetically significant dose is defined as the gonad dose which, if received by every member of the population, would result in the same total genetic effect to the population as the doses which are actually received by individuals within the population. The genetically significant dose for the U.S. population (1964) was found to be 55 millirads per person per year. This value is higher than that for other countries.

The contribution to the genetically significant dose from radiography was 96 percent, with 4 percent from fluoroscopy and less than 1 percent from photofluorography. The largest single population group contributing to GSD was males 15 to 29 years of age.

It was estimated that restriction of the X-ray beam to an area no larger than the film size would result in a reduction of the genetically significant dose from 55 to 19 millirads per person per year.

GLOSSARY

GLOSSARY

Absorbed dose - as referred to in this report is the quantity of energy that is imparted to the gonads when exposed to radiation.

Age - was recorded for each person in the household interview survey as of his last birthday. Age was recorded in single years and grouped for presentation in this report. Age specific rates shown on charts are plotted at the midpoints of the groups.

Backscatter - is radiation deflected by scattering processes through angles greater than 90 degrees with respect to the original direction of motion.

Beam alignment - was estimated from the densities recorded on radiographic film packs used in the Study. The beam alignment values represent the distance between the recorded beam center and the center of the film pack.

Beam area - was recorded on film packs and represents the area exposed to the direct radiation from the X-ray tube at the plane of the patient or at the plane of the film.

Body area - was coded for each X-ray procedure other than dental. The area of the body to which the X-rays were directed is classified into one of the following categories:

- Head and neck - that portion of the body above the trunk.
- Chest - that portion of the trunk above the diaphragm including the shoulder.
- Abdomen - the remainder of the trunk including the hip.
- Upper extremities - arms, including hands, but exclusive of the shoulders.
- Lower extremities - legs, including feet, but exclusive of the hips.

Effective beam size - that portion of the X-ray beam which is limited to the area of the receptor film.

Examination - refers to the inspection or investigation of a specific body area, or overlapping body areas, during an X-ray procedure. X-ray examinations as used in this report refer to diagnostic or screening procedures.

Exposure - is used technically in this report to refer to the measurement of X-rays in terms of Roentgens as defined by the International Commission on Radiological Units and Measurements (32). In accordance with common practice, "exposure" is sometimes used synonymously with a film. It is also used in general terms referring to experience; for example, population exposure to X-rays.

Exposure factors - refer to X-ray machine settings used in an examination or procedure. The factors include such items as: kilovolt peak, milliamperes, time, and source-to-film distance.

Exposure ratio - refers to exposure relationship between a known exposure to a given surface unit area and the percent contribution to gonadal exposure.

Facility - refers to the place where an X-ray examination or procedure was performed. In this report facilities are grouped as: hospitals (inpatient, outpatient, and associated clinics), private (one man) offices, private groups or clinics (more than one man), mobile units, health departments, and other types (voluntary health agencies, industrial clinics, Federal Government clinics, and so forth).

Film - refers to a single radiographic (including dental), photofluorographic or "spot" exposure. During the collection of data, when more than one exposure was reported on a single film, each exposure was counted as a separate film and the film size adjusted accordingly.

Filtration - refers to the material placed in the X-ray beam to absorb the less penetrating radiation. In this report, filtration is expressed in units of millimeters of aluminum equivalent. Total filtration comprises: *inherent filtration* introduced by the window of the X-ray tube and any permanently attached material in the beam, and *added filtration* introduced by any additional material placed in the beam.

Genetically significant dose (GSD) - is defined as the gonad dose which, if received by every member of the population, would be expected to produce the same total genetic effect on the population as the sum of the individual doses actually received.

Indirect dosimetry - refers to the collection of dosimetric information by means of report forms and film packs and the use of these data in conjunction with laboratory-developed models for the estimation of exposure and dose.

Medical - refers to all X-ray visits, examinations, procedures, and films, other than dental, recorded in the Study. This includes radiography, photofluorography, fluoroscopy, and therapy performed by medical and osteopathic physicians, chiropractors, chiropodists, podiatrists, and other practitioners for the purpose of diagnosis or treatment.

Primary beam - refers to that radiation coming directly from the target of an X-ray tube.

Procedure - is used in this report to refer to both diagnostic X-ray examinations and therapy techniques.

Radiographic - was used in the Study to refer to X-ray examinations other than fluoroscopic or dental. This application, therefore, includes photofluorographic exposures which have been shown as separate estimates wherever possible.

Skin entrance - refers to the site, on the surface of the body, at which the useful beam will penetrate.

Spot films - refer to the radiographs made using the same tube as the one employed during a related fluoroscopic examination. Other radiographic films related to a fluoroscopic examination, but exposed on another X-ray tube, were classified separately as "radiographic."

Useful beam - refers to that part of the primary radiation which passes through the aperture, cone, or other collimator of an X-ray unit.

X-ray visit - is a visit by a person to a physician's or dentist's office, hospital, mobile X-ray unit, public health department, or other X-ray facility during which X-ray equipment was used for diagnosis or treatment.

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APPENDIX

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Table 1. Estimated mean gonad dose per examination by type of examination and sex, United States, 1964

Type of examination	Male	Female	Fetus
	Millirads per examination		
Skull	-	4	7
Cervical spine	8	2	3
Chest			
Radiographic	5	8	6
Photofluorographic	-	8	8
Fluoroscopic	1	71	(*)
Thoracic spine	184	9	9
Shoulder	-	-	-
Upper gastrointestinal series			
Radiographic	130	360	343
Fluoroscopic	7	198	198
Barium enema			
Radiographic	1,535	439	417
Fluoroscopic	50	366	397
Cholecystography or cholangiogram	2	193	206
Intravenous or retrograde pyelogram	2,091	407	451
Abdomen, KUB, flat plate	254	289	291
Lumbar spine – lumbo-sacral	2,547	420	239
Pelvis or lumbo-pelvic	717	41	82
Hip	1,064	309	366
Upper extremities	2	1	(*)
Lower extremities	96	-	-
All other			
Radiographic	52	92	251
Fluoroscopic	229	-	-

363-953 O - 69 - 8

Table 2. Quartile distribution of gonad doses by type of radiographic examination and sex, United States, 1964

Type of examination	Male			Female		
	First quartile[a]	Median	Third quartile[b]	First quartile[a]	Median	Third quartile[b]
	Millirads per examination					
Skull	-	-	-	-	-	-
Cervical spine	-	-	-	-	-	-
Chest						
Radiographic	-	-	-	-	-	4
Photofluorographic	-	-	-	1	4	12
Thoracic spine	-	-	2	(*)	(*)	(*)
Shoulder	-	-	-	-	-	-
Upper gastrointestinal series	3	7	25	108	301	536
Barium enema	99	878	2,071	94	396	756
Cholecystography or cholangiogram	-	1	2	16	105	146
Intravenous or retrograde pyelogram	376	869	3,125	173	443	624
Abdomen, KUB, flat plate	13	13	646	71	254	522
Lumbar spine – lumbo-sacral	6	24	907	13	339	490
Pelvis or lumbo-pelvic	52	553	942	(*)	(*)	(*)
Hip	569	926	1,468	(*)	(*)	(*)
Upper extremities	-	-	-	-	-	-
Lower extremities	-	-	4	-	-	-
All other radiographic	-	-	24	-	12	267

[a] First quartile - value below which 25 percent of doses lie.

[b] Third quartile - value below which 75 percent of doses lie.

Table 3. Estimated annual number of medical X-ray examinations by age and sex, United States, 1964 (base for genetic dose calculations)

Age	Total	Male	Female	Fetus
Total	90,707	54,370	35,218	1,119
Under 15	16,419	9,379	5,921	---
15 – 29	23,826	12,495	11,331	---
30 – 44	26,267	13,269	12,998	---
45 – 59[a]	24,195	19,227	4,968	---

[a] 45 – 49 for females.

Table 4. Expected future number of children for selected age–sex groups, United States, 1964

Age	Male	Female
Fetus	3.18	3.18
0 – 4	3.26	3.09
5 – 9	3.37	3.17
10 – 14	3.38	3.18
15 – 19	3.39	3.18
20 – 24	3.33	2.82
25 – 29	2.49	1.73
30 – 34	1.43	.84
35 – 39	.70	.32
40 – 44	.30	.07
45 – 49	.11	.01
50 – 54	.04	---
55 – 59	.02	---

Table 5. Comparison of reported annual genetically significant dose from diagnostic radiology (selected countries)

Study	Genetically significant dose in millirads	Examinations per 100 population	Genetically significant dose per examination
United States (1964)	55	53	1.04
Sweden (1955)	38	29	1.31
Japan (1960)	39	41	.95
Denmark (1956)	22	24	.92
Great Britain (1957)	14	28	.50
New Zealand (1963)	12	37	.32

Table 6. Comparison of genetically significant dose per examination with expected future number of children

Age	Genetically significant dose in millirads (1)	Percentage distribution of GSD (2)	Number of examinations (3)	Percentage distribution of examinations (4)	GSD per examination in age group relative to GSD per examination for all ages (5)	Expected future number of children (6)
Total	54.6	100.0	122,184	100.0		
Fetus	.9	1.6	6,711	5.5	.29	3.18
Under 15	4.3	7.8	15,293	12.5	.62	3.27
15 – 29	38.9	71.2	23,881	19.5	3.65	2.83
30 – 44	9.8	18.1	26,267	21.5	.84	.55
45 and over	.7	1.3	50,032	41.0	-	.05

Table 7. Estimated mean annual genetically significant dose contributions by sex and type of examination, United States, 1964

Type of examination	Total	Male	Female	Fetus
	Millirads per examination			
Total	54.6	45.4	8.3	0.9
Skull	-	-	-	-
Cervical spine	-	-	-	-
Chest				
Radiographic	.7	.3	.4	-
Photofluorographic	.2	-	.2	-
Fluoroscopic	.1	-	.1	(*)
Thoracic spine	1.3	1.3	-	-
Shoulder	-	-	-	-
Upper gastrointestinal series				
Radiographic	1.7	1.0	.7	-
Fluoroscopic	.7	-	.7	-
Barium enema				
Radiographic	7.9	6.3	1.6	-
Fluoroscopic	1.5	.2	1.3	-
Cholecystography or cholangiogram	.2	-	.2	-
Intravenous or retrograde pyelogram	6.6	5.1	1.4	.1
Abdomen, KUB, flat plate	2.9	2.0	.4	.5
Lumbar spine — lumbo-sacral	22.0	21.4	.6	-
Pelvis or lumbo-pelvic	4.0	3.8	-	.2
Hip	.9	.8	.1	(*)
Upper extremities	.1	.1	-	(*)
Lower extremities	2.6	2.6	-	-
All other	1.2	.5	.6	.1

Table 8. Estimated mean annual genetically significant dose contributions for males by age and type of examination, United States, 1964

Type of examination	Under 15	15 – 29	30 – 44	45 – 59
	Millirads per examination			
Total	3.1	33.2	8.4	.7
Skull	-	(*)	(*)	-
Cervical spine	(*)	(*)	(*)	-
Chest				
Radiographic	.1	.3	-	-
Photofluorographic	(*)	(*)	(*)	-
Fluoroscopic	-	-	-	-
Thoracic spine	-	1.3	-	-
Shoulder	(*)	-	(*)	(*)
Upper gastrointestinal series				
Radiographic	-	.5	.4	-
Fluoroscopic	-	-	-	-
Barium enema				
Radiographic	.3	4.7	1.2	.1
Fluoroscopic	-	.1	.1	-
Cholecystography or cholangiogram	-	-	-	-
Intravenous or retrograde pyelogram	.7	2.7	1.3	.4
Abdomen, KUB, flat plate	.8	1.1	.1	-
Lumbar spine – lumbo-sacral	-	16.5	4.8	.1
Pelvis or lumbo-pelvic	.5	3.0	.3	-
Hip	-	.7	-	.1
Upper extremities	-	.1	(*)	(*)
Lower extremities	.3	2.2	.1	-
All other	.4	-	.1	-

Table 9. Estimated mean annual genetically significant dose contributions for females by age and type of examination, United States, 1964

Type of examination	Under 15	15 – 29	30 – 44	45 – 49	Fetus
	Millirads per examination				
Total	1.2	5.7	1.4	-	.9
Skull	(*)	(*)	-	-	-
Cervical spine	(*)	(*)	-	(*)	-
Chest					
Radiographic	.3	.1	-	-	-
Photofluorographic	-	.1	-	-	-
Fluoroscopic	-	-	-	-	(*)
Thoracic spine	-	-	-	-	-
Shoulder	(*)	(*)	-	(*)	-
Upper gastrointestinal series					
Radiographic	-	.4	.3	-	-
Fluoroscopic	(*)	.5	.1	-	-
Barium enema					
Radiographic	.4	1.0	.2	-	-
Fluoroscopic	.2	1.1	.1	-	-
Cholecystography or cholangiogram	-	.1	.1	-	-
Intravenous or retrograde pyelogram	.2	1.1	.2	-	.1
Abdomen, KUB, flat plate	-	.2	.2	-	.5
Lumbar spine – lumbo-sacral	(*)	.5	.1	-	-
Pelvis or lumbo-pelvic	-	(*)	-	-	.2
Hip	.1	-	-	-	(*)
Upper extremities	-	(*)	(*)	(*)	(*)
Lower extremities	-	-	-	(*)	-
All other	-	.6	.1	-	.1

Table 10. Comparison of genetically significant dose by country: percentage and cumulative percentage distributions by type of examination

Type of examination	United States (1964)		New Zealand (1957)		Sweden (1955)		Great Britain (1957)		Denmark (1956)	
	% Dist.	Cum. % Dist.	% Dist.	Cum. % Dist.	% Dist.	Cum. % Dist.	% Dist.	Cum. % Dist.	% Dist.	Cum. % Dist.
Total	100.0		100.0		100.0		100.0		100.0	
Lumbar and lumbo-sacral spine	40.3	40.3	24.9[a]	24.9	20.6	20.6	23.5[a]	23.5	5.9	5.9
Barium enema	17.1	57.4	8.9	33.8	7.4	28.0			8.5	14.4
Intravenous or retrograde pyelogram	12.1	69.5	16.0	49.8	18.7	46.7	13.1	36.6	14.9	29.3
Pelvis	7.4	76.9	6.2[a]	56.0	28.7	75.4	8.7[a]	45.3	23.0	52.3
Abdomen	5.2	82.1	32.8	88.8	7.4	82.8	30.1	75.4	19.7	72.0
Lower extremities	4.8	86.9	2.8	91.6	4.0	86.8			6.0	78.0
Thoracic spine	2.3	89.2	.3	91.9	-	86.8			.1	78.1
Upper gastrointestinal series	4.5	93.7	3.7	95.6	.8	87.6	3.9	79.3	2.2	80.3
Chest	1.9	95.6	.3	95.9	1.1	88.7	3.6	82.9	4.1	84.4
Hip	1.6	97.2	3.8	99.7	6.6	95.3	11.2	94.1	12.7	97.1
Others	2.8	100.0	.3	100.0	4.7	100.0	5.9[b]	100.0	2.9	100.0

[a] These two examinations were combined in the original report.

[b] Barium enema, lower extremities, and thoracic spine included in others.

Table 11. Estimated mean gonad dose per examination by sex and type of examination, simulated beam size = reported film size, United States, 1964

Type of examination	Male	Female	Fetus
	Millirads per examination		
Skull	-	-	-
Cervical spine	-	-	-
Chest			
Radiographic	-	3.6	2.6
Photofluorographic	3.3	-	-
Fluoroscopic	1.4	70.5	-
Thoracic spine	1.7	5.3	1.1
Shoulder	-	-	-
Upper gastrointestinal series			
Radiographic	7.8	357.7	386.6
Fluoroscopic	6.6	198.4	197.5
Barium enema			
Radiographic	1,055.0	432.5	421.1
Fluoroscopic	49.5	366.4	397.1
Cholecystography or cholangiogram	-	109.0	127.5
Intravenous or retrograde pyelogram	657.2	392.0	429.2
Abdomen, KUB, flat plate	170.0	265.4	263.9
Lumbar spine	20.0	439.6	409.8
Pelvis or lumbo-pelvic	327.2	39.8	79.8
Hip	148.8	273.6	331.9
Upper extremities	1.5	.9	2.5
Lower extremities	86.6	-	-
All other			
Radiographic	49.7	195.2	229.4
Fluoroscopic	229.0	-	-

Table 12. Estimated mean annual genetically significant dose by sex and type of examination, simulated beam size = reported film size, United States, 1964

Type of examination	Total	Male	Female	Fetus
	Millirads per examination			
Total	19.4	9.5	9.3	0.6
Skull	-	-	-	-
Cervical spine	-	-	-	-
Chest				
Radiographic	.2	-	.2	-
Photofluorographic	-	-	-	-
Fluoroscopic	-	-	-	-
Thoracic spine	-	-	-	-
Shoulder	-	-	-	-
Upper gastrointestinal series				
Radiographic	1.0	-	1.0	-
Fluoroscopic	.7	-	.7	-
Barium enema				
Radiographic	2.7	1.2	1.5	-
Fluoroscopic	1.4	.1	1.3	-
Cholecystography or cholangiogram	.1	-	.1	-
Intravenous or retrograde pyelogram	4.0	2.6	1.4	-
Abdomen, KUB, flat plate	1.4	.7	.3	.4
Lumbar spine	1.3	.1	1.2	-
Pelvis or lumbo-pelvic	1.9	1.8	-	.1
Hip	.1	-	.1	-
Upper extremities	.1	.1	-	-
Lower extremities	2.2	2.2	-	-
All other	2.3	.7	1.5	.1

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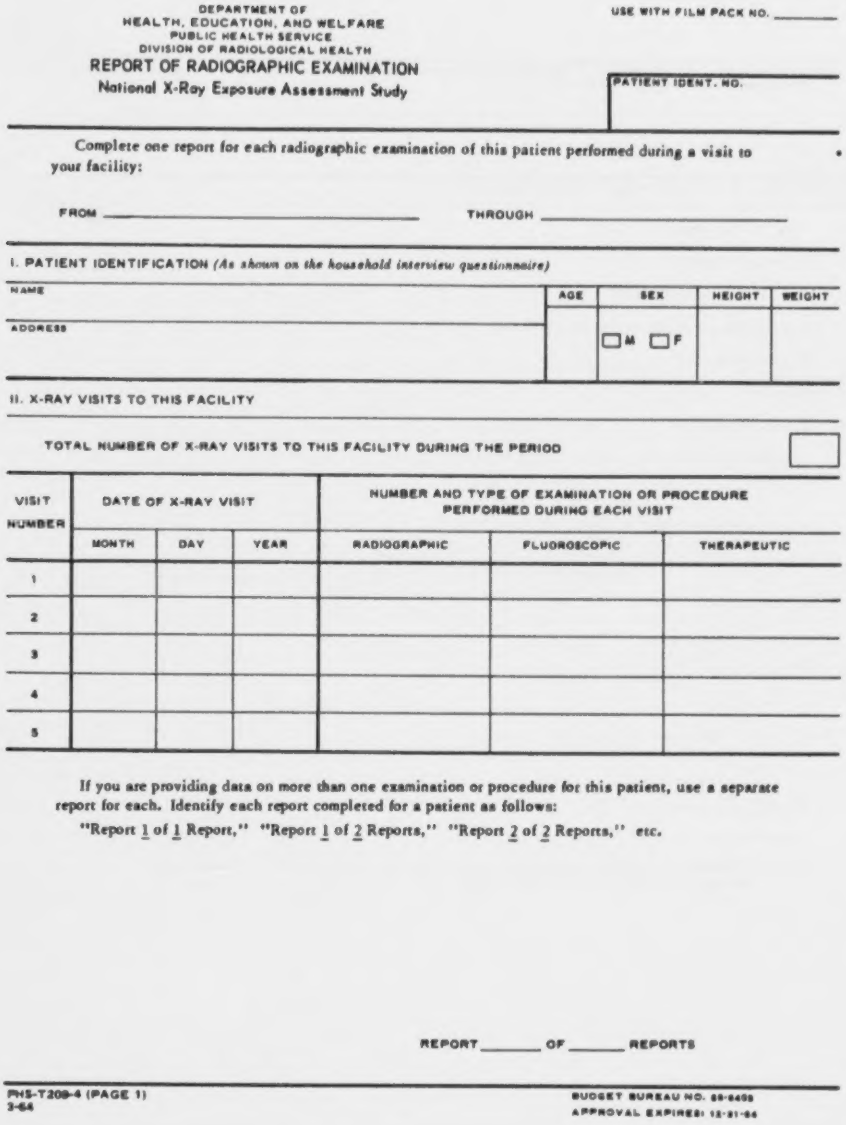
EXHIBITS



DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
DIVISION OF RADIOLOGICAL HEALTH

REPORT OF RADIOGRAPHIC EXAMINATION
National X-Ray Exposure Assessment Study

USE WITH FILM PACK NO. ______

PATIENT IDENT. NO.

Complete one report for each radiographic examination of this patient performed during a visit to your facility:

FROM ______________ THROUGH ______________

I. PATIENT IDENTIFICATION *(As shown on the household interview questionnaire)*

NAME	AGE	SEX	HEIGHT	WEIGHT
ADDRESS		☐ M ☐ F		

II. X-RAY VISITS TO THIS FACILITY

TOTAL NUMBER OF X-RAY VISITS TO THIS FACILITY DURING THE PERIOD ☐

VISIT NUMBER	DATE OF X-RAY VISIT			NUMBER AND TYPE OF EXAMINATION OR PROCEDURE PERFORMED DURING EACH VISIT		
	MONTH	DAY	YEAR	RADIOGRAPHIC	FLUOROSCOPIC	THERAPEUTIC
1						
2						
3						
4						
5						

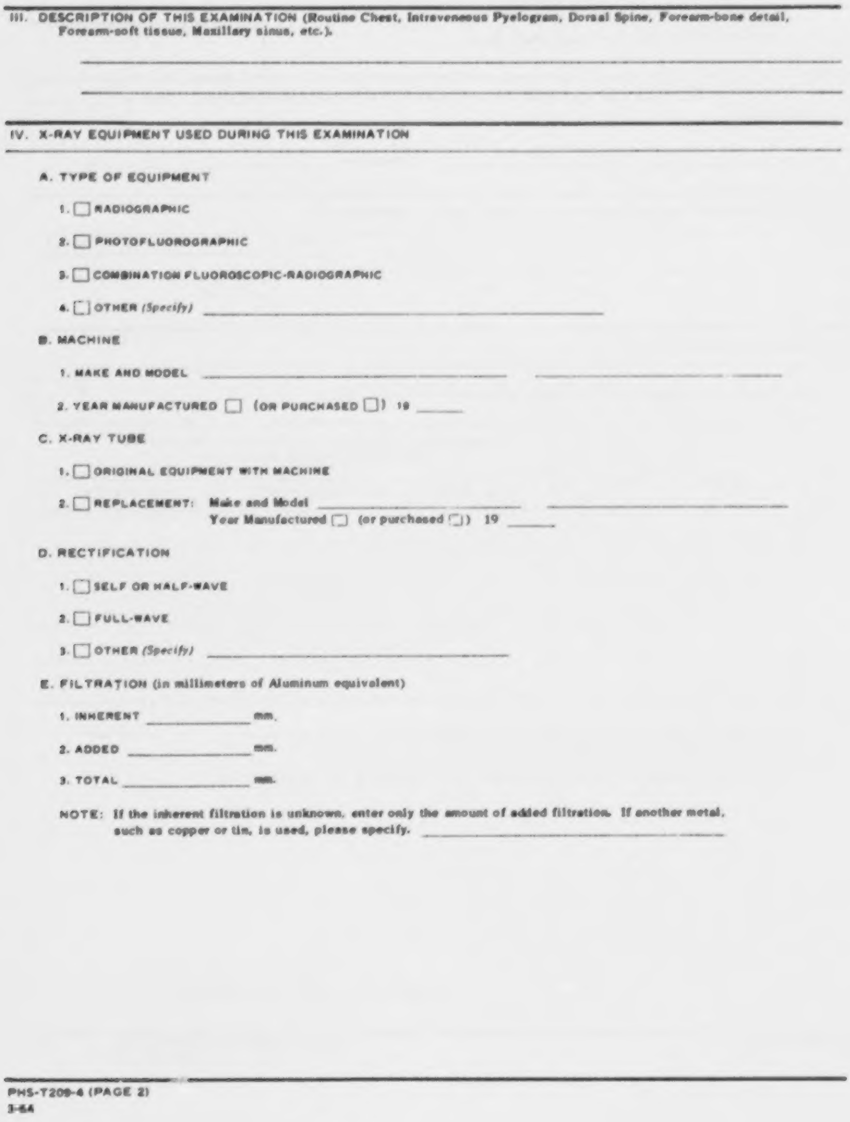
If you are providing data on more than one examination or procedure for this patient, use a separate report for each. Identify each report completed for a patient as follows:
"Report 1 of 1 Report," "Report 1 of 2 Reports," "Report 2 of 2 Reports," etc.

REPORT ______ OF ______ REPORTS

PHS-T209-4 (PAGE 1)
3-64

BUDGET BUREAU NO. 68-6408
APPROVAL EXPIRES: 12-31-64

EXHIBIT 1.—Report of Radiographic Examination.



III. DESCRIPTION OF THIS EXAMINATION (Routine Chest, Intravenous Pyelogram, Dorsal Spine, Forearm-bone detail, Forearm-soft tissue, Maxillary sinus, etc.).

____

____

IV. X-RAY EQUIPMENT USED DURING THIS EXAMINATION

A. TYPE OF EQUIPMENT

1. ☐ RADIOGRAPHIC
2. ☐ PHOTOFLUOROGRAPHIC
3. ☐ COMBINATION FLUOROSCOPIC-RADIOGRAPHIC
4. ☐ OTHER *(Specify)* ________________

B. MACHINE

1. MAKE AND MODEL ________________ ________________
2. YEAR MANUFACTURED ☐ (OR PURCHASED ☐) 19 ______

C. X-RAY TUBE

1. ☐ ORIGINAL EQUIPMENT WITH MACHINE
2. ☐ REPLACEMENT: Make and Model ________________ ________________
   Year Manufactured ☐ (or purchased ☐) 19 ______

D. RECTIFICATION

1. ☐ SELF OR HALF-WAVE
2. ☐ FULL-WAVE
3. ☐ OTHER *(Specify)* ________________

E. FILTRATION (in millimeters of Aluminum equivalent)

1. INHERENT ________ mm.
2. ADDED ________ mm.
3. TOTAL ________ mm.

NOTE: If the inherent filtration is unknown, enter only the amount of added filtration. If another metal, such as copper or tin, is used, please specify. ________________

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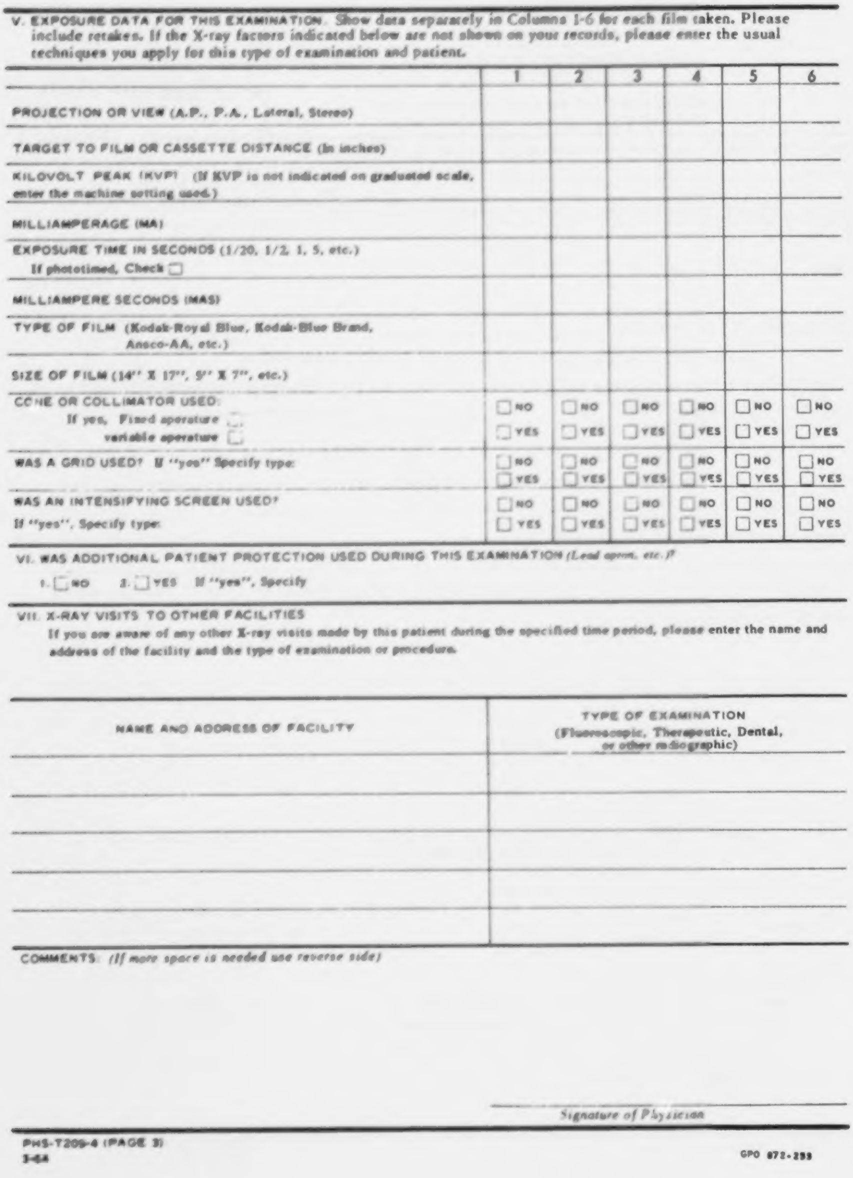
3-64

EXHIBIT 1.—Continued.



V. EXPOSURE DATA FOR THIS EXAMINATION. Show data separately in Columns 1-6 for each film taken. Please include retakes. If the X-ray factors indicated below are not shown on your records, please enter the usual techniques you apply for this type of examination and patient.

	1	2	3	4	5	6
PROJECTION OR VIEW (A.P., P.A., Lateral, Stereo)						
TARGET TO FILM OR CASSETTE DISTANCE (In inches)						
KILOVOLT PEAK (KVP) (If KVP is not indicated on graduated scale, enter the machine setting used.)						
MILLIAMPERAGE (MA)						
EXPOSURE TIME IN SECONDS (1/20, 1/2, 1, 5, etc.) If phototimed, Check ☐						
MILLIAMPERE SECONDS (MAS)						
TYPE OF FILM (Kodak-Royal Blue, Kodak-Blue Brand, Ansco-AA, etc.)						
SIZE OF FILM (14" X 17", 5" X 7", etc.)						
CONE OR COLLIMATOR USED: If yes, Fixed aperature ☐ variable aperature ☐	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES
WAS A GRID USED? If "yes" Specify type:	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES
WAS AN INTENSIFYING SCREEN USED? If "yes", Specify type:	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES

VI. WAS ADDITIONAL PATIENT PROTECTION USED DURING THIS EXAMINATION *(Lead apron, etc.)?*

1. ☐ NO 2. ☐ YES If "yes", Specify

VII. X-RAY VISITS TO OTHER FACILITIES

If you are aware of any other X-ray visits made by this patient during the specified time period, please enter the name and address of the facility and the type of examination or procedure.

NAME AND ADDRESS OF FACILITY	TYPE OF EXAMINATION (Fluoroscopic, Therapeutic, Dental, or other radiographic)

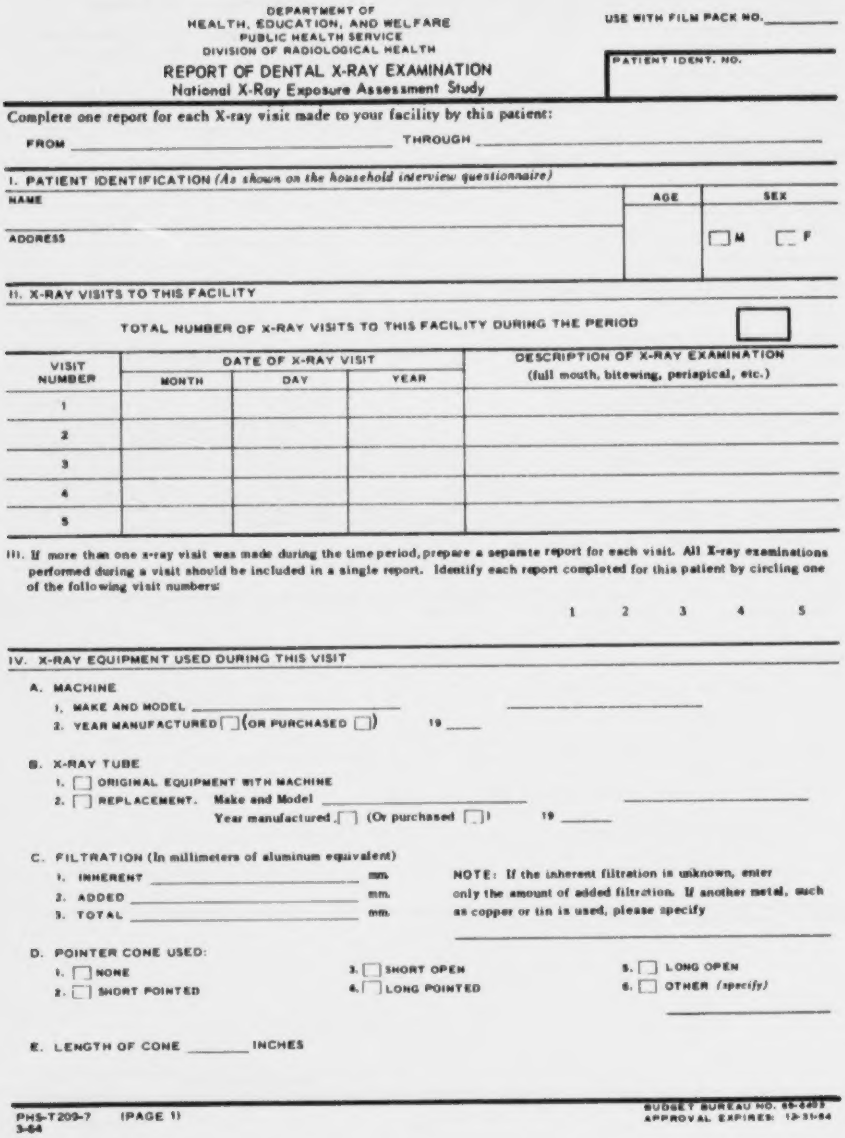
COMMENTS: *(If more space is needed use reverse side)*

Signature of Physician

PHS-T209-4 (PAGE 3)
3-64

GPO 872-293

EXHIBIT 1.—Continued.



DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
DIVISION OF RADIOLOGICAL HEALTH

REPORT OF DENTAL X-RAY EXAMINATION
National X-Ray Exposure Assessment Study

USE WITH FILM PACK NO.________

PATIENT IDENT. NO.

Complete one report for each X-ray visit made to your facility by this patient:

FROM ____________________ THROUGH ____________________

I. PATIENT IDENTIFICATION *(As shown on the household interview questionnaire)*

NAME	AGE	SEX
ADDRESS		☐ M ☐ F

II. X-RAY VISITS TO THIS FACILITY

TOTAL NUMBER OF X-RAY VISITS TO THIS FACILITY DURING THE PERIOD ☐

VISIT NUMBER	DATE OF X-RAY VISIT			DESCRIPTION OF X-RAY EXAMINATION (full mouth, bitewing, periapical, etc.)
	MONTH	DAY	YEAR	
1				
2				
3				
4				
5				

III. If more than one x-ray visit was made during the time period, prepare a separate report for each visit. All X-ray examinations performed during a visit should be included in a single report. Identify each report completed for this patient by circling one of the following visit numbers:

1 2 3 4 5

IV. X-RAY EQUIPMENT USED DURING THIS VISIT

A. MACHINE
1. MAKE AND MODEL ________________ ________________
2. YEAR MANUFACTURED ☐ (OR PURCHASED ☐) 19 ____

B. X-RAY TUBE
1. ☐ ORIGINAL EQUIPMENT WITH MACHINE
2. ☐ REPLACEMENT. Make and Model ________________ ________________
Year manufactured ☐ (Or purchased ☐) 19 ____

C. FILTRATION (In millimeters of aluminum equivalent)
1. INHERENT ________________ mm.
2. ADDED ________________ mm.
3. TOTAL ________________ mm.

NOTE: If the inherent filtration is unknown, enter only the amount of added filtration. If another metal, such as copper or tin is used, please specify ________________

D. POINTER CONE USED:
1. ☐ NONE
2. ☐ SHORT POINTED
3. ☐ SHORT OPEN
4. ☐ LONG POINTED
5. ☐ LONG OPEN
6. ☐ OTHER *(specify)* ________________

E. LENGTH OF CONE ______ INCHES

PHS-T209-7 (PAGE 1)
3-64

BUDGET BUREAU NO. 68-6403
APPROVAL EXPIRES: 12-31-64

EXHIBIT 2.—Report of Dental X-ray Examination.

V. EXPOSURE DATA FOR THIS VISIT

If the X-ray factors indicated below are not shown on your records, please enter the usual technique you apply for this type of examination and patient. Show data separately in columns 1-6 for each film or group of films for which different factors were used. Please include retakes.

	1	2	3	4	5	6
PROJECTION (Lateral, periapical occlusal, bitewing, etc.)						
EXPOSURE TIME IN SECONDS (1/10, 1/2, 1, 2, etc.)						
TYPE OF FILM (Dupont 25 D-1, Kodak DF-13, Minimax EFD, etc.)						
KILOVOLT PEAK (KVP) If KVP is not indicated on graduated scale, enter the machine setting used.						
MILLIAMPERAGE (MA)						
NUMBER OF FILMS TAKEN USING THESE FACTORS						
TEETH INVOLVED (Upper incisors, lower molars, upper cuspids, upper bicuspids, etc.)						

VI. WAS ADDITIONAL PATIENT PROTECTION USED DURING THIS EXAMINATION *(lead apron, etc.)*

1. ☐ NO 2. ☐ YES If "yes," specify: ______________________

VII. X-RAY VISITS TO OTHER FACILITIES

If you are aware of any other X-rays visits made by this patient during the specified time period, please enter the name and address of the facility and the type of examination or procedure.

NAME AND ADDRESS OF FACILITY	TYPE OF EXAMINATION (Fluoroscopic, therapeutic, dental, or other radiographic.)

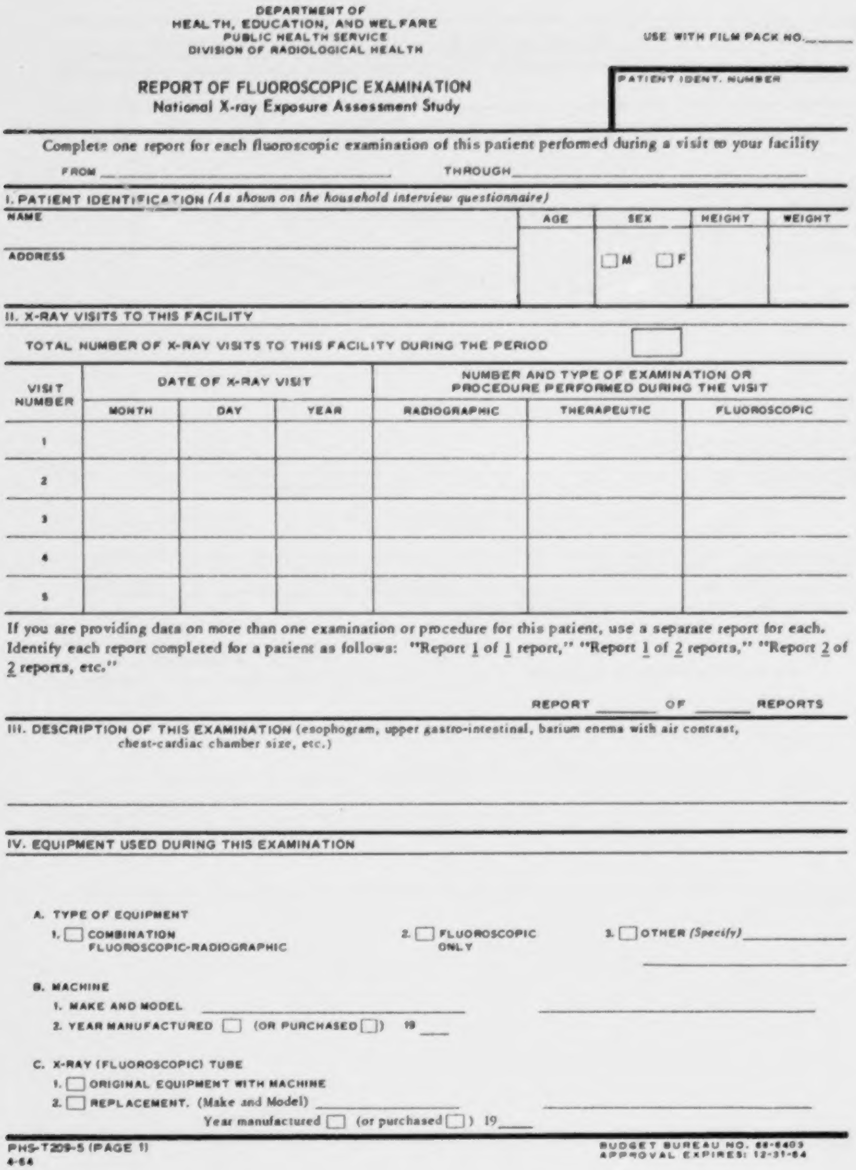
COMMENTS

____
(Signature of Dentist)

PHS-T209-7 (PAGE 2)
3-64

GPO 873-806

EXHIBIT 2.—Continued.



DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
DIVISION OF RADIOLOGICAL HEALTH

USE WITH FILM PACK NO.______

REPORT OF FLUOROSCOPIC EXAMINATION
National X-ray Exposure Assessment Study

PATIENT IDENT. NUMBER

Complete one report for each fluoroscopic examination of this patient performed during a visit to your facility

FROM ____________________ THROUGH ____________________

I. PATIENT IDENTIFICATION *(As shown on the household interview questionnaire)*

NAME	AGE	SEX	HEIGHT	WEIGHT
ADDRESS		☐ M ☐ F		

II. X-RAY VISITS TO THIS FACILITY

TOTAL NUMBER OF X-RAY VISITS TO THIS FACILITY DURING THE PERIOD ☐

VISIT NUMBER	DATE OF X-RAY VISIT			NUMBER AND TYPE OF EXAMINATION OR PROCEDURE PERFORMED DURING THE VISIT		
	MONTH	DAY	YEAR	RADIOGRAPHIC	THERAPEUTIC	FLUOROSCOPIC
1						
2						
3						
4						
5						

If you are providing data on more than one examination or procedure for this patient, use a separate report for each. Identify each report completed for a patient as follows: "Report 1 of 1 report," "Report 1 of 2 reports," "Report 2 of 2 reports, etc."

REPORT ______ OF ______ REPORTS

III. DESCRIPTION OF THIS EXAMINATION (esophogram, upper gastro-intestinal, barium enema with air contrast, chest-cardiac chamber size, etc.)

IV. EQUIPMENT USED DURING THIS EXAMINATION

A. TYPE OF EQUIPMENT
1. ☐ COMBINATION FLUOROSCOPIC-RADIOGRAPHIC
2. ☐ FLUOROSCOPIC ONLY
3. ☐ OTHER *(Specify)* __________

B. MACHINE
1. MAKE AND MODEL ____________________
2. YEAR MANUFACTURED ☐ (OR PURCHASED ☐) 19___

C. X-RAY (FLUOROSCOPIC) TUBE
1. ☐ ORIGINAL EQUIPMENT WITH MACHINE
2. ☐ REPLACEMENT. (Make and Model) ____________________
Year manufactured ☐ (or purchased ☐) 19____

PHS-T209-5 (PAGE 1)
4-64

BUDGET BUREAU NO. 68-6403
APPROVAL EXPIRES: 12-31-64

EXHIBIT 3.—Report of Fluoroscopic Examination.

IV. EQUIPMENT USED DURING THIS EXAMINATION (Continued)

D. FLUOROSCOPIC SCREEN
1. ☐ ORIGINAL EQUIPMENT WITH MACHINE
2. ☐ REPLACEMENT. YEAR MANUFACTURED ☐ (OR PURCHASED ☐) 19 ______

E. IMAGE INTENSIFIER
1. ☐ NOT USED
2. ☐ USED. MAKE AND MODEL ____________________ ____________________
YEAR MANUFACTURED ☐ (OR PURCHASED ☐) 19 ______

F. RECTIFICATION
1. ☐ SELF OR HALF-WAVE
2. ☐ FULL WAVE
3. ☐ OTHER *(Specify)* ________________________________

G. FILTRATION (In millimeters of Aluminum equivalent) **NOTE:** If the inherent filtration is unknown, enter only the amount of added filtration. If another metal, such as copper or tin, is used, please specify ____________

1. INHERENT __________ mm. 2. ADDED __________ mm. 3. TOTAL __________ mm.

V. EXPOSURE DATA FOR THIS EXAMINATION

If the factors outlined below are not shown on your records, please enter the usual technique you apply for this type of examination and patient:

A. PREDOMINANT IMAGE SIZE ON FLUOROSCOPIC SCREEN __________ X __________ INCHES

B. PREDOMINANT DISTANCE OF FLUOROSCOPIC SCREEN FROM TABLE TOP __________ INCHES

C. KILOVOLT PEAK (KVP) USED FOR THIS EXAMINATION ____________________.

D. MILLIAMPERES (MA) USED FOR THIS EXAMINATION ____________________.

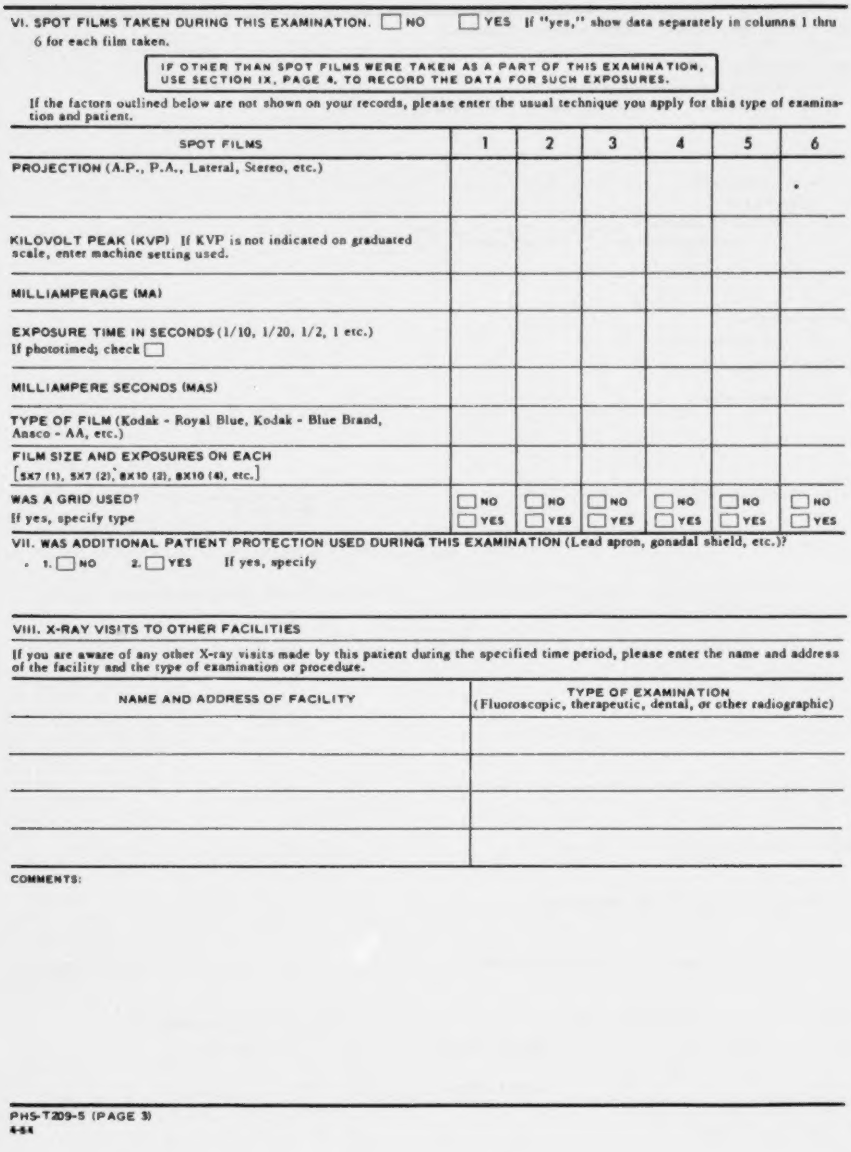
E. ESTIMATED TOTAL EXPOSURE TIME FOR THIS EXAMINATION ____________________ MINUTES (2½, 4, 5¼, ETC.)

F. POSITION OF PATIENT DURING EXAMINATION (Please estimate percent of examination time in each position.)

SUPINE ________ %	RIGHT LATERAL ________ %	OTHER *(Specify)* ________ %
PRONE ________ %	LEFT LATERAL ________ %	________ %

PHS-T209-5 (PAGE 2)
4-64

EXHIBIT 3.—Continued.



VI. SPOT FILMS TAKEN DURING THIS EXAMINATION. ☐ NO ☐ YES If "yes," show data separately in columns 1 thru 6 for each film taken.

IF OTHER THAN SPOT FILMS WERE TAKEN AS A PART OF THIS EXAMINATION, USE SECTION IX, PAGE 4, TO RECORD THE DATA FOR SUCH EXPOSURES.

If the factors outlined below are not shown on your records, please enter the usual technique you apply for this type of examination and patient.

SPOT FILMS	1	2	3	4	5	6
PROJECTION (A.P., P.A., Lateral, Stereo, etc.)						
KILOVOLT PEAK (KVP) If KVP is not indicated on graduated scale, enter machine setting used.						
MILLIAMPERAGE (MA)						
EXPOSURE TIME IN SECONDS (1/10, 1/20, 1/2, 1 etc.) If phototimed; check ☐						
MILLIAMPERE SECONDS (MAS)						
TYPE OF FILM (Kodak - Royal Blue, Kodak - Blue Brand, Ansco - AA, etc.)						
FILM SIZE AND EXPOSURES ON EACH [5X7 (1), 5X7 (2), 8X10 (2), 8X10 (4), etc.]						
WAS A GRID USED? If yes, specify type	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES

VII. WAS ADDITIONAL PATIENT PROTECTION USED DURING THIS EXAMINATION (Lead apron, gonadal shield, etc.)?

1. ☐ NO 2. ☐ YES If yes, specify

VIII. X-RAY VISITS TO OTHER FACILITIES

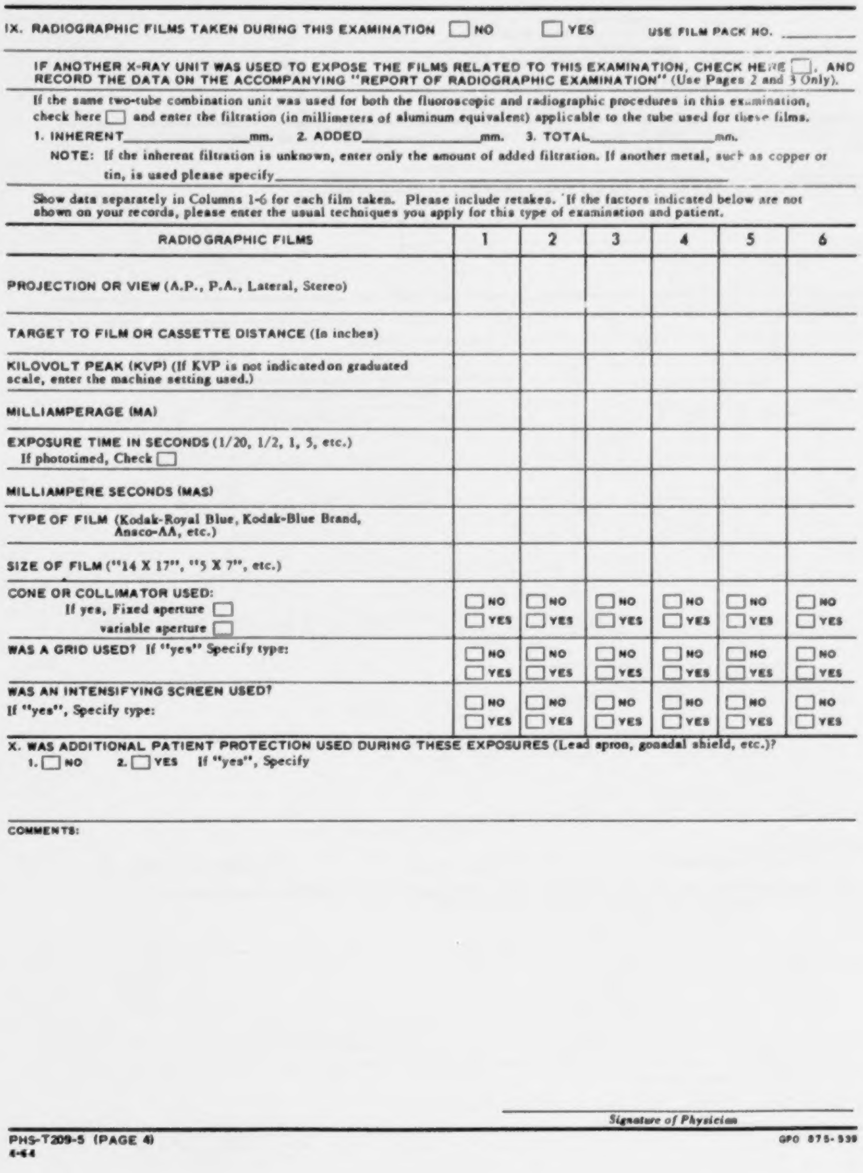
If you are aware of any other X-ray visits made by this patient during the specified time period, please enter the name and address of the facility and the type of examination or procedure.

NAME AND ADDRESS OF FACILITY	TYPE OF EXAMINATION (Fluoroscopic, therapeutic, dental, or other radiographic)

COMMENTS:

PHS-T209-5 (PAGE 3)
4-64

EXHIBIT 3.—Continued.



IX. RADIOGRAPHIC FILMS TAKEN DURING THIS EXAMINATION ☐ NO ☐ YES USE FILM PACK NO. ________

IF ANOTHER X-RAY UNIT WAS USED TO EXPOSE THE FILMS RELATED TO THIS EXAMINATION, CHECK HERE ☐, AND RECORD THE DATA ON THE ACCOMPANYING "REPORT OF RADIOGRAPHIC EXAMINATION" (Use Pages 2 and 3 Only).

If the same two-tube combination unit was used for both the fluoroscopic and radiographic procedures in this examination, check here ☐ and enter the filtration (in millimeters of aluminum equivalent) applicable to the tube used for these films.

1. INHERENT ________mm. 2. ADDED ________mm. 3. TOTAL ________mm.

NOTE: If the inherent filtration is unknown, enter only the amount of added filtration. If another metal, such as copper or tin, is used please specify ________

Show data separately in Columns 1-6 for each film taken. Please include retakes. If the factors indicated below are not shown on your records, please enter the usual techniques you apply for this type of examination and patient.

RADIOGRAPHIC FILMS	1	2	3	4	5	6
PROJECTION OR VIEW (A.P., P.A., Lateral, Stereo)						
TARGET TO FILM OR CASSETTE DISTANCE (In inches)						
KILOVOLT PEAK (KVP) (If KVP is not indicated on graduated scale, enter the machine setting used.)						
MILLIAMPERAGE (MA)						
EXPOSURE TIME IN SECONDS (1/20, 1/2, 1, 5, etc.) If phototimed, Check ☐						
MILLIAMPERE SECONDS (MAS)						
TYPE OF FILM (Kodak-Royal Blue, Kodak-Blue Brand, Ansco-AA, etc.)						
SIZE OF FILM ("14 X 17", "5 X 7", etc.)						
CONE OR COLLIMATOR USED: If yes, Fixed aperture ☐ variable aperture ☐	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES
WAS A GRID USED? If "yes" Specify type:	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES
WAS AN INTENSIFYING SCREEN USED? If "yes", Specify type:	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES

X. WAS ADDITIONAL PATIENT PROTECTION USED DURING THESE EXPOSURES (Lead apron, gonadal shield, etc.)?
1. ☐ NO 2. ☐ YES If "yes", Specify

COMMENTS:

____
Signature of Physician

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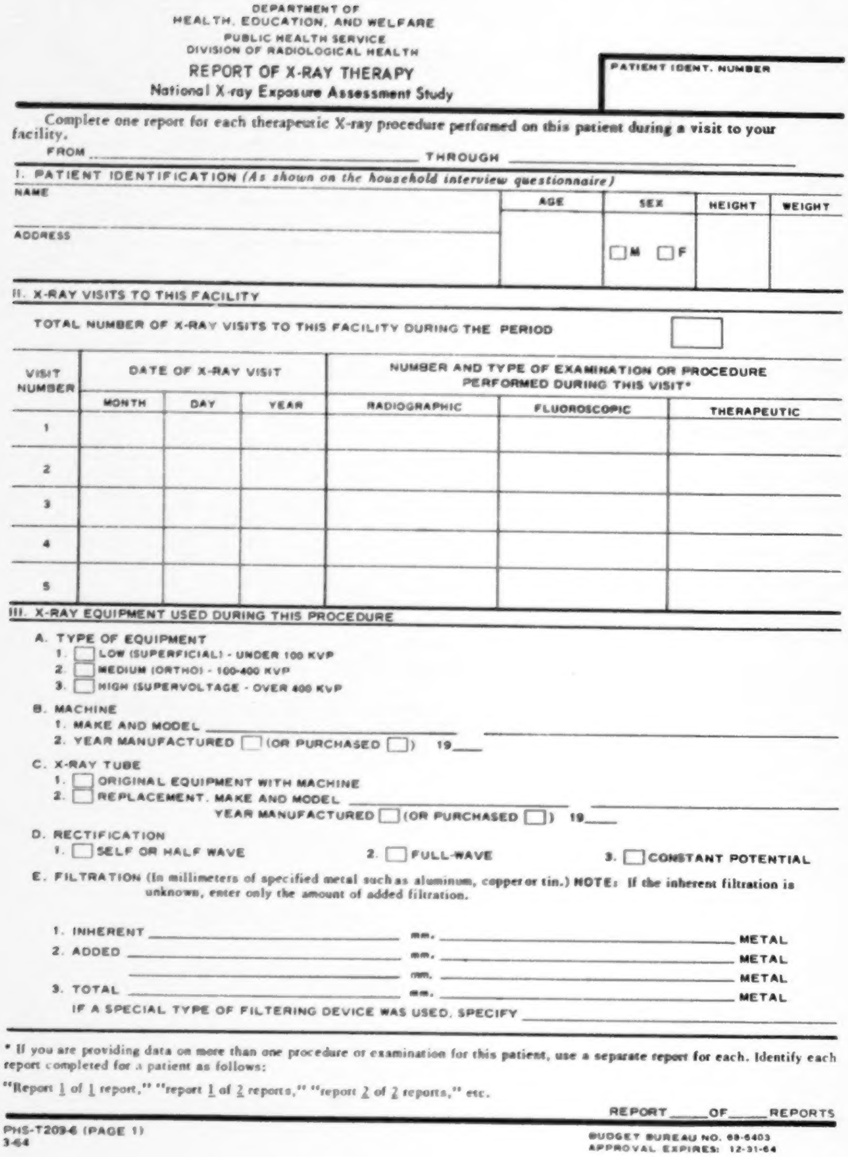
4-64

GPO 875-539

EXHIBIT 3.—Continued.



DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
DIVISION OF RADIOLOGICAL HEALTH

REPORT OF X-RAY THERAPY
National X-ray Exposure Assessment Study

PATIENT IDENT. NUMBER

Complete one report for each therapeutic X-ray procedure performed on this patient during a visit to your facility.

FROM ____________________ THROUGH ____________________

I. PATIENT IDENTIFICATION *(As shown on the household interview questionnaire)*

NAME	AGE	SEX	HEIGHT	WEIGHT
ADDRESS		☐ M ☐ F		

II. X-RAY VISITS TO THIS FACILITY

TOTAL NUMBER OF X-RAY VISITS TO THIS FACILITY DURING THE PERIOD ☐

VISIT NUMBER	DATE OF X-RAY VISIT			NUMBER AND TYPE OF EXAMINATION OR PROCEDURE PERFORMED DURING THIS VISIT*		
	MONTH	DAY	YEAR	RADIOGRAPHIC	FLUOROSCOPIC	THERAPEUTIC
1						
2						
3						
4						
5						

III. X-RAY EQUIPMENT USED DURING THIS PROCEDURE

A. TYPE OF EQUIPMENT
  1. ☐ LOW (SUPERFICIAL) - UNDER 100 KVP
  2. ☐ MEDIUM (ORTHO) - 100-400 KVP
  3. ☐ HIGH (SUPERVOLTAGE - OVER 400 KVP

B. MACHINE
  1. MAKE AND MODEL ____________________ ____________________
  2. YEAR MANUFACTURED ☐ (OR PURCHASED ☐) 19___

C. X-RAY TUBE
  1. ☐ ORIGINAL EQUIPMENT WITH MACHINE
  2. ☐ REPLACEMENT. MAKE AND MODEL ____________________ ____________________
  YEAR MANUFACTURED ☐ (OR PURCHASED ☐) 19___

D. RECTIFICATION
  1. ☐ SELF OR HALF WAVE 2. ☐ FULL-WAVE 3. ☐ CONSTANT POTENTIAL

E. FILTRATION (In millimeters of specified metal such as aluminum, copper or tin.) **NOTE:** If the inherent filtration is unknown, enter only the amount of added filtration.

  1. INHERENT ____________________ mm. ____________________ METAL
  2. ADDED ____________________ mm. ____________________ METAL
  ____________________ mm. ____________________ METAL
  3. TOTAL ____________________ mm. ____________________ METAL
  IF A SPECIAL TYPE OF FILTERING DEVICE WAS USED, SPECIFY ____________________

* If you are providing data on more than one procedure or examination for this patient, use a separate report for each. Identify each report completed for a patient as follows:

"Report 1 of 1 report," "report 1 of 2 reports," "report 2 of 2 reports," etc.

REPORT ____ OF ____ REPORTS

PHS-T209-6 (PAGE 1)
3-64

BUDGET BUREAU NO. 68-6403
APPROVAL EXPIRES: 12-31-64

EXHIBIT 4.—Report of X-ray Therapy.

IV. EXPOSURE DATA FOR THIS PROCEDURE: Show data separately in columns 1-6 for each entrance port used in this procedure. If the X-ray factors outlined below are not available in your records, please enter the usual technique you apply for this type of procedure and patient.

In the case of repeated visits, (during the specified time period) involving identical procedures, report the exposure data once only and indicate the number of visits for these procedures under comments.

	1	2	3	4	5	6
ANATOMICAL SITE						
SIZE OF ENTRANCE PORT ☐ IN. ☐ CM.						
TARGET TO SKIN DISTANCE ☐ IN. ☐ CM.						
KILOVOLT PEAK (KVP) If Kilovoltage is not indicated on graduated scale, enter the machine setting used.						
MILLIAMPERAGE (MA)						
EXPOSURE TIME IN SECONDS						
DOSE RATE AT SKIN IN R/MIN						
CONE OR COLLIMATOR USED? If yes, circular ☐, Rectangular ☐	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES
Inside diameter or dimensions of opening at: Base ☐ IN. ☐ CM.						
Tip ☐ IN. ☐ CM.						
Perpendicular length ☐ IN. ☐ CM.						
CONE TIP TO SKIN DISTANCE ☐ IN. ☐ CM.						

V. WAS ADDITIONAL PATIENT PROTECTION USED DURING THIS EXAMINATION *(lead apron, etc.)?*

1. ☐ NO 2. ☐ YES If yes, specify____________________

VI. X-RAY VISITS TO OTHER FACILITIES

If you are aware of any other X-ray visits made by this patient during the specified time period, please enter the name and address of the facility and the type of examination or procedure.

NAME AND ADDRESS OF FACILITY	TYPE OF EXAMINATION (Fluoroscopic, therapeutic, dental, other radiographic)

COMMENTS

____
Signature of Physician

PHS-T209-6 (PAGE-2)
3-64

EXHIBIT 4.—Continued.

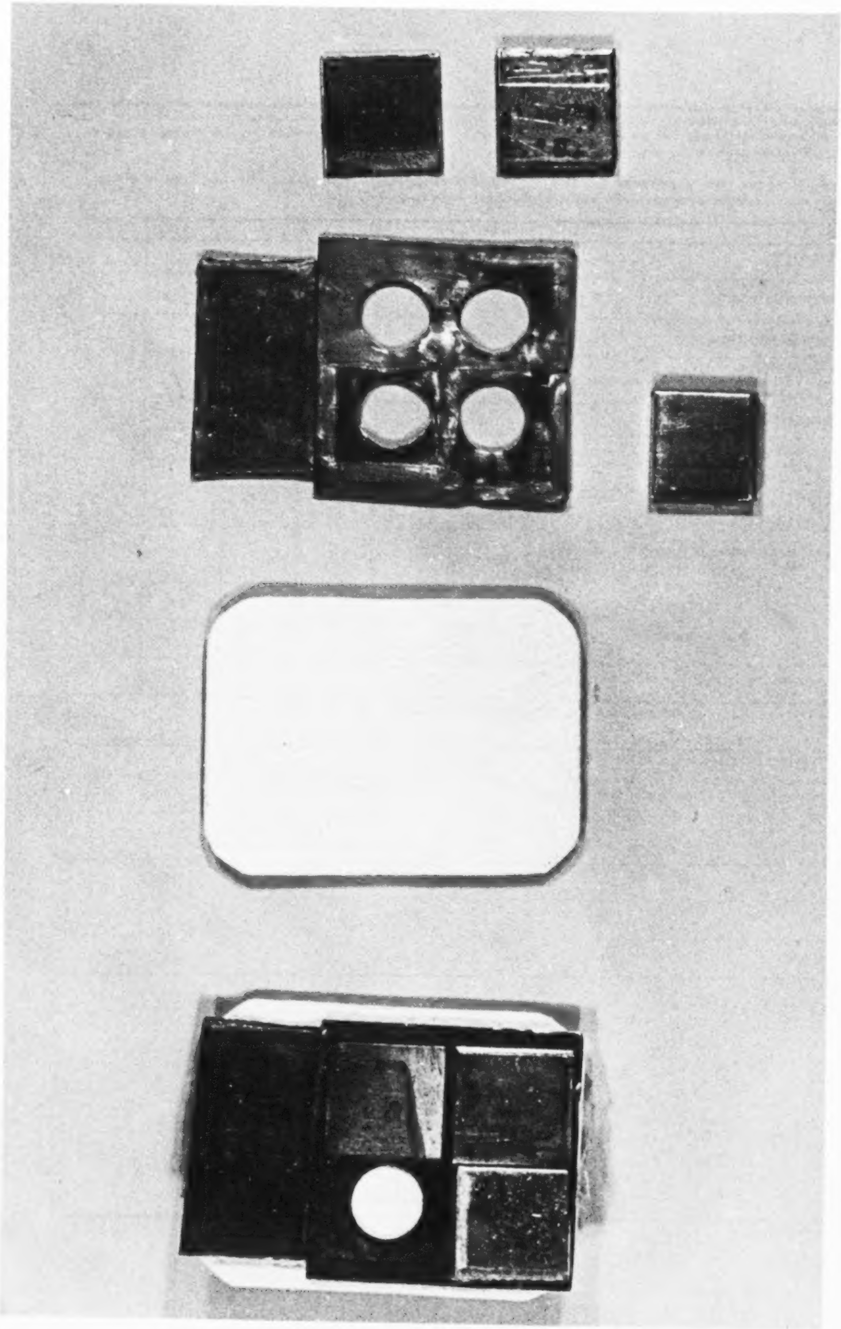


EXHIBIT 5.—Sensitometric Film Packet.

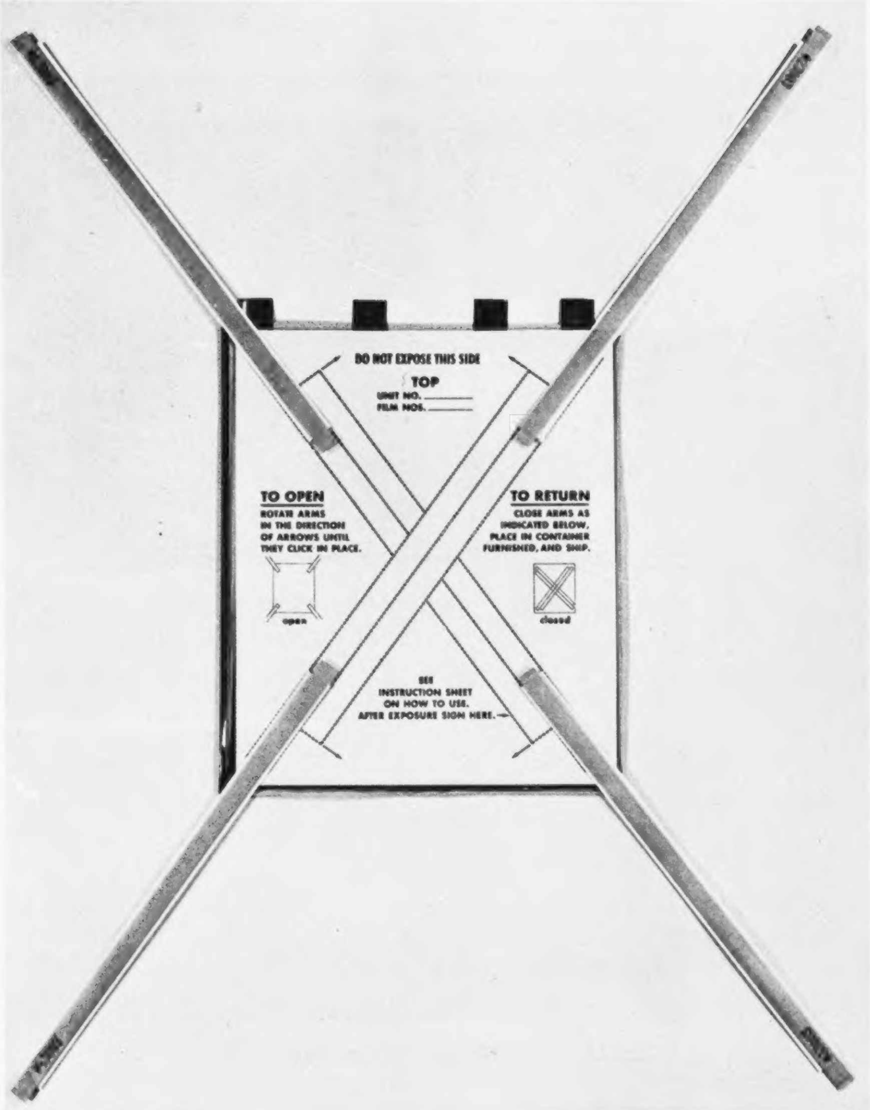

DO NOT EXPOSE THIS SIDE
TOP
UNIT NO. ________
FILM NOS. ________
TO OPEN
ROTATE ARMS IN THE DIRECTION OF ARROWS UNTIL THEY CLICK IN PLACE.
open
TO RETURN
CLOSE ARMS AS INDICATED BELOW, PLACE IN CONTAINER FURNISHED, AND SHIP.
closed
SEE INSTRUCTION SHEET ON HOW TO USE.
AFTER EXPOSURE SIGN HERE.

EXHIBIT 6.—Radiographic Film Pack.

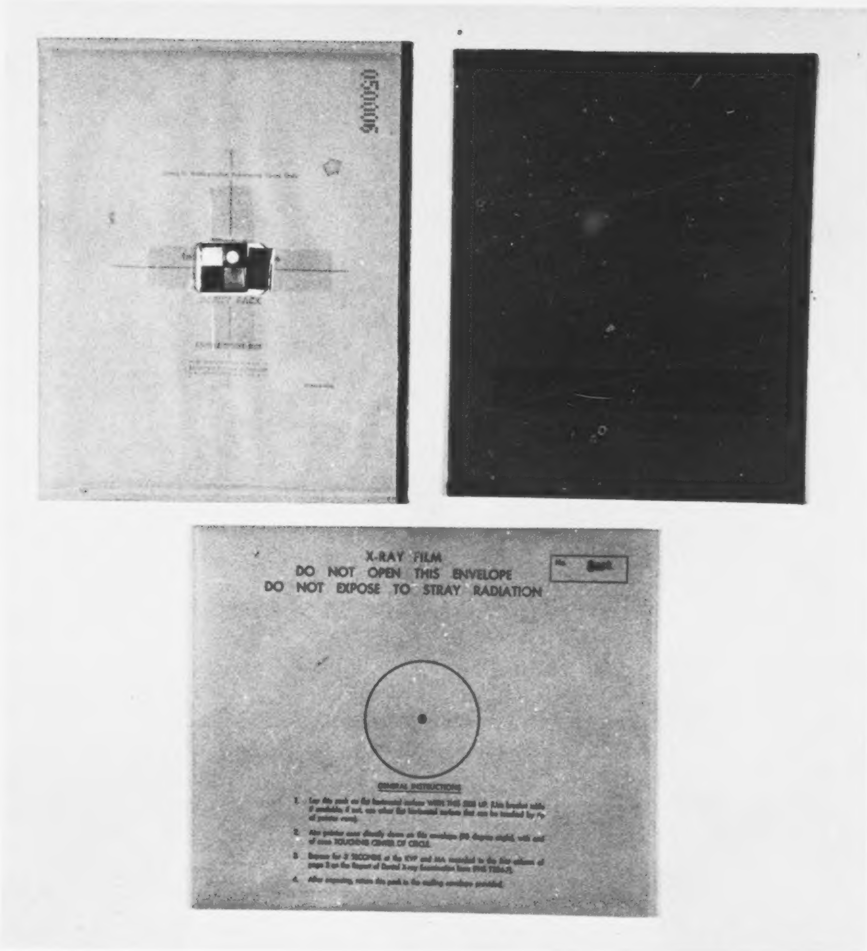

X-RAY FILM
DO NOT OPEN THIS ENVELOPE
DO NOT EXPOSE TO STRAY RADIATION
GENERAL INSTRUCTIONS

EXHIBIT 7.—Dental Film Pack.

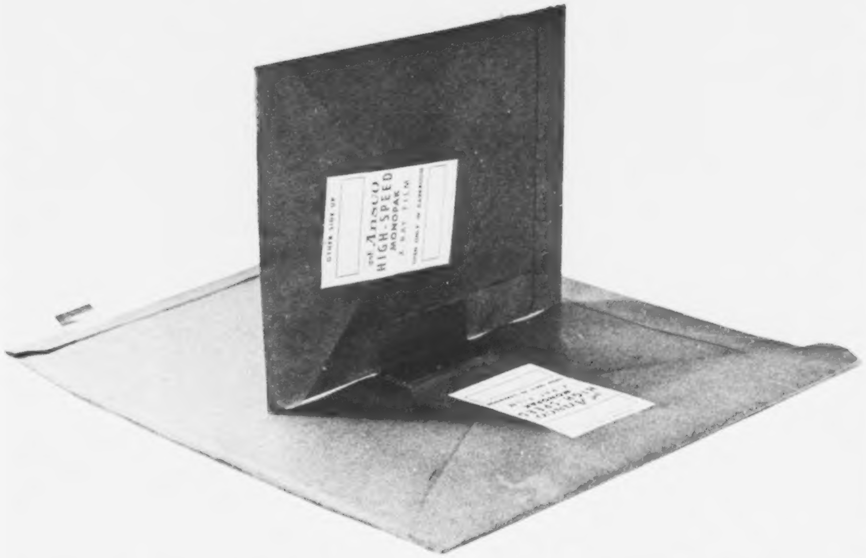

Ansco
HIGH SPEED
MONOPAK
X-RAY FILM

EXHIBIT 8.-Dual-Fluoroscopic Film Pack.

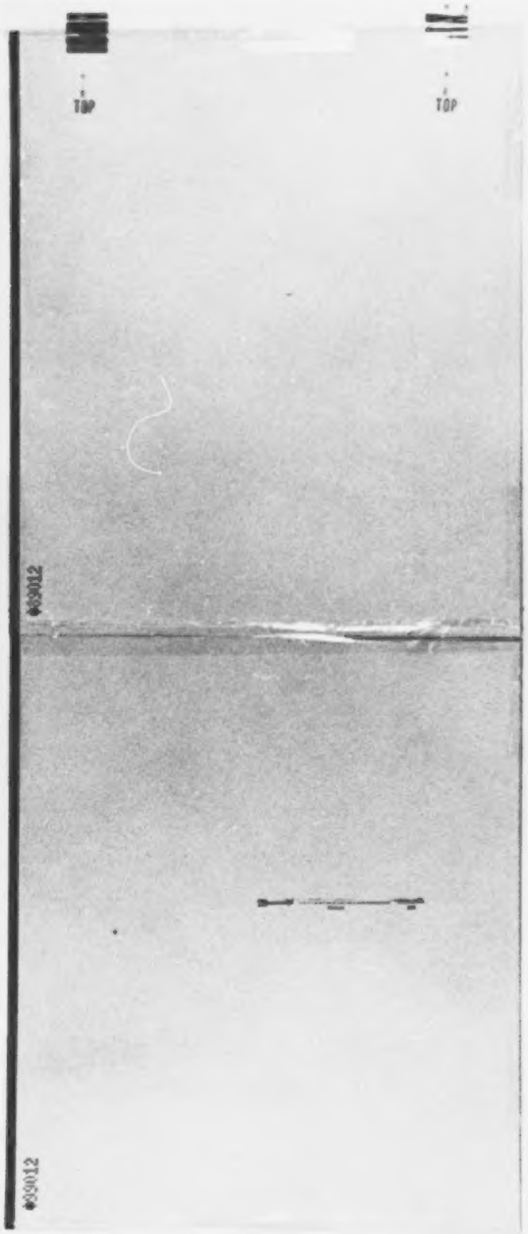

TOP
TOP
39012
39012

EXHIBIT 9.—Fluoroscopic Record Film Pack.

EXHIBIT 10.—Measuring Beam Size Recorded on Radiographic Film Packs.

Total filtration (millimeters of Al equivalent)	Kilovolt peak								
	50	55	60	65	70	75	80	85	90
0.5	91.11	96.03	101.44	107.59	114.73	123.10	132.94	144.49	158.00
1.0	58.38	63.32	68.54	74.27	80.75	88.24	96.98	107.20	119.15
1.5	36.61	41.64	46.72	52.09	57.99	64.66	72.35	81.30	91.75
2.0	23.26	28.45	33.45	38.52	43.89	49.81	56.52	64.25	73.27
2.5	15.79	21.19	26.19	31.01	35.92	41.14	46.93	53.52	61.16
3.0	11.65	17.33	22.37	27.02	31.52	36.12	41.04	46.55	52.88
3.5	8.30	14.32	19.47	24.01	28.17	32.19	36.32	40.80	45.88
4 0	3.19	9.61	14.94	19.43	23.30	26.82	30.21	33.73	37.62
4.5	---	.67	6.24	10.73	14.39	17.46	20.18	22.80	25.56

EXHIBIT 11.—Mean Milliroentgens per Milliampere-second at 12 Inches by Kilovolt Peak and Filtration Categories for Dental X-ray Units.

Total filtration (millimeters of Al equivalent)	Kilovolt peak						Kilovolt peak—Continued					
	45	50	55	60	65	70	75	80	85	90	95	100
0.5	67.02	78.58	89.90	101.16	112.51	124.11	136.14	148.76	162.12	176.40	191.76	208.36
1.0	43.25	52.83	62.16	71.41	80.74	90.31	100.30	110.86	122.16	134.36	147.63	162.14
1.5	27.62	35.49	43.10	50.62	58.21	66.03	74.26	83.04	92.56	102.96	114.42	127.10
2.0	18.35	24.80	30.97	37.04	43.17	49.52	56.25	63.54	71.55	80.43	90.36	101.49
2.5	13.69	18.99	24.00	28.90	33.84	38.99	44.52	50.59	57.37	65.01	73.68	83.55
3.0	11.87	16.29	20.42	24.43	28.46	32.70	37.30	42.43	48.25	54.93	62.63	71.51
3.5	11.12	14.96	18.48	21.87	25.28	28.88	32.83	37.29	42.44	48.43	55.43	63.61
4.0	9.69	13.21	16.41	19.46	22.52	25.76	29.33	33.41	38.17	43.75	50.33	58.07
4.5	5.81	9.29	12.44	15.43	18.42	21.57	25.06	29.03	33.66	39.12	45.56	53.15

EXHIBIT 12.—Mean Milliroentgens per Milliampere-second at 12 Inches by Kilovolt Peak and Filtration Categories for Nondental X-ray Units.

Body part	Children 17 years and under	Adults 18 years and over					
		Females			Males		
		Small	Medium	Large	Small	Medium	Large
Weight/height ratio range	......	<2.05	2.05–2.32	>2.32	<2.31	2.31–2.57	>2.57
ANTERIOR-POSTERIOR MEASUREMENTS							
Head	7.0	6.1	7.1	7.8	6.7	7.6	8.0
Neck	3.5	3.1	3.5	3.9	4.7	4.9	5.4
Thorax—chest	6.0	7.0	7.8	8.9	7.8	9.1	10.8
Upper abdomen	5.5	5.4	6.5	9.4	7.2	8.7	10.0
Lower abdomen	7.0	6.4	8.3	9.5	7.8	8.8	9.7
Upper extremity	2.0	1.5	2.5	2.5	2.5	2.8	3.1
Upper arm	3.0	2.1	3.3	3.9	3.4	3.9	4.3
Elbow	2.5	1.7	2.7	3.3	2.9	3.2	3.6
Forearm	1.5	1.5	2.0	2.5	3.0	3.4	3.7
Wrist	1.5	1.3	1.7	2.1	2.1	2.2	2.4
Hand	0.8	1.0	1.1	1.1	1.1	1.3	1.4
Lower extremity	3.0	3.3	4.1	4.4	3.9	4.2	4.3
Thigh	4.5	4.5	6.0	6.6	5.4	5.5	6.0
Knee	3.5	3.5	4.7	3.7	4.5	4.8	4.8
Calf	2.5	3.3	3.2	5.1	4.2	4.8	4.7
Ankle	2.5	2.9	3.5	3.6	3.0	3.3	3.7
Foot	2.0	2.4	3.0	3.1	2.5	2.8	2.8
LATERAL MEASUREMENTS							
Head	5.5	5.3	5.8	6.2	6.0	6.2	7.1
Neck	3.5	3.4	4.5	4.7	4.9	4.9	5.3
Thorax—chest	9.5	10.0	11.1	12.1	10.6	12.1	13.4
Upper abdomen	8.5	6.9	8.8	10.3	9.7	10.3	12.6
Lower abdomen	10.0	11.7	13.2	16.7	12.4	13.2	14.2
Upper extremity	2.0	2.4	2.7	2.9	2.9	3.1	3.4
Upper arm	3.0	2.5	3.3	3.5	3.2	3.6	3.6
Elbow	2.0	2.5	2.5	2.9	3.0	3.4	3.7
Forearm	2.0	2.1	2.1	2.9	3.0	3.3	3.7
Wrist	1.5	2.1	2.1	2.5	1.8	2.0	2.4
Hand	2.5	2.6	2.9	3.1	3.2	3.5	3.8
Lower extremity	3.0	3.2	3.9	4.1	3.4	4.2	4.4
Thigh	5.0	3.9	5.8	4.9	4.6	5.6	5.4
Knee	3.0	3.5	3.8	4.0	3.9	4.5	4.8
Calf	2.5	3.2	3.3	4.1	3.1	4.3	4.8
Ankle	2.5	2.1	2.9	3.7	2.5	3.0	3.3
Foot	3.0	3.1	3.6	4.0	2.9	3.6	3.8

EXHIBIT 13.—Anthropometric Data, Composite, Body Part Thickness (inches).

363-953 O - 69 - 10

Type of examination	Milliroentgens (at skin entrance)					
	All	Hospitals	Private offices: Radiologists	Private offices: Others	Private groups	Health agencies and others
Head and neck	279	277	341	277	256	(*)
Skull	304	312	(*)	(*)	(*)	(*)
Cervical spine	158	113	(*)	294	(*)	(*)
Examinations of head and neck, n.e.c.	370	363	(*)	(*)	(*)	(*)
Thorax	—	—	—	—	—	—
Chest, photofluorographic	504	408	(*)	(*)	(*)	521
Chest, radiographic	45	43	34	44	43	92
Shoulder	213	193	(*)	(*)	(*)	(*)
Thoracic spine and cervical spine	1,265	1,371	(*)	(*)	(*)	(*)
Examinations of chest or thorax, n.e.c.	1,657	1,998	(*)	(*)	(*)	(*)
Abdomen	790	743	636	1,253	736	1,484
Upper abdomen	796	747	533	1,475	684	(*)
Cholecystography or cholangiogram	771	740	(*)	(*)	612	(*)
Lumbar spine or dorsolumbar spine	1,965	2,005	(*)	2,295	(*)	(*)
Upper gastrointestinal series	519	514	456	(*)	567	(*)
Gastrointestinal, n.e.c.	521	466	(*)	(*)	(*)	(*)
Examinations of upper abdomen, n.e.c.	363	365	(*)	(*)	(*)	(*)
Lower abdomen	784	738	770	1,102	789	(*)
Barium enema	629	652	530	(*)	(*)	(*)
Abdomen, KUB, flat plate	771	773	(*)	(*)	(*)	(*)
Intra or retrograde pyelogram	481	468	(*)	597	444	(*)
Pelvis or lumbo-pelvic	487	438	(*)	(*)	(*)	(*)
Lumbosacral or sacral spine	2,449	2,466	(*)	(*)	(*)	(*)
Hip	1,036	1,279	(*)	(*)	(*)	(*)
Extremities	117	118	113	138	63	73
Upper extremities	127	136	(*)	134	49 (*)	(*) (*)
Hand and/or wrist	82	93	(*)	76		
Forearm or elbow	125	86	(*)	279	(*)	(*)
Lower extremities	110	105	(*)	141	71	(*)
Ankle	109	104	(*)	165	(*)	(*)
Foot and toes or heel	126	104	(*)	195	(*)	(*)
Knee	93	85	(*)	79	(*)	(*)
Tibia and fibula	44	47	(*)	(*)	(*)	(*)
Femur or entire leg	187	202	(*)	(*)	(*)	(*)

---

[1] Includes photofluorographic exposures.

EXHIBIT 14.—Estimated Mean Exposure per Film by Type of Radiographic Examination and Type of Facility, United States, 1964.

Sex and age	Milliroentgens (at skin entrance)					
	Type of examination					
	All types	Bite-wing	Bite-wing and peri-apical	Full mouth	Peri-apical	All other
Both Sexes	1, 138	1, 249	1, 170	1, 059	1, 201	1, 302
Under 15	876	1, 067	600	763	865	1, 339
15–29	1, 149	1, 324	1, 417	939	1, 375	(*)
30–44	1, 153	1, 161	1, 372	1, 078	1, 319	(*)
45 and over	1, 377	1, 635	1, 204	1, 385	1, 167	(*)
45–64	1, 397	1, 669	1, 179	1, 379	1, 244	(*)
65 and over	1, 246	1, 249	(*)	1, 433	978	(*)
Male	1, 134	1, 122	1, 175	1, 136	1, 141	746
Under 15	833	996	471	839	683	(*)
15–29	1, 021	1, 357	1, 377	723	1, 202	(*)
30–44	1, 205	1, 131	1, 844	1, 096	1, 354	(*)
45 and over	1, 517	997	922	1, 825	1, 417	(*)
45–64	1, 518	1, 024	824	1, 888	1, 043	(*)
65 and over	1, 513	(*)	(*)	1, 399	2, 473	(*)
Female	1, 141	1, 345	1, 166	997	1, 248	1, 828
Under 15	912	1, 137	754	714	1, 017	(*)
15–29	1, 252	1, 301	1, 459	1, 109	1, 533	(*)
30–44	1, 110	1, 184	998	1, 063	1, 286	(*)
45 and over	1, 274	1, 960	1, 373	969	1, 203	(*)
45–64	1, 305	2, 009	1, 373	923	1, 410	(*)
65 and over	1, 069	1, 494	(*)	1, 482	736	(*)

EXHIBIT 15.—Estimated Mean Exposure per Dental Film by Type of Examination, Sex, and Age, United States, 1964.

Person number	Height	Weight	Sex	Distance from vertex to							Skull		Thorax		Abdomen		Pub.sym. thickness
				Nasion	Ext. aud. canal	Sternal notch	Xiphoid process	Bi-iliac crest	Pubic sym.	Knee	Thick-ness	Width	Thick-ness	Width	Thick-ness	Width	
	(cm)	(kg)		(cm)							(cm)						
1	186.8	72.6	M	8.1	12.2	31.3	49.2	72.5	85.8	132.6	19.0	15.8	23.0	31.1	20.0	29.8	16.0
2	172.6	71.7	M	10.6	14.2	30.4	49.7	69.6	83.0	121.3	20.0	16.7	22.5	37.0	20.0	34.0	18.0
3	180.3	95.3	M	10.3	13.0	31.4	47.0	72.4	88.0	126.6	19.0	16.0	25.5	32.4	25.5	38.0	19.0
4	186.5	81.2	M	9.4	13.3	34.0	53.6	78.5	94.2	133.7	20.6	16.4	22.0	31.0	22.3	33.2	18.2
5	178.7	64.9	M	7.8	13.8	32.2	51.7	70.2	88.8	127.9	19.2	16.3	21.0	33.5	17.0	27.7	18.0
6	171.5	49.0	M	7.0	12.8	31.2	49.7	65.8	82.9	120.6	18.5	14.5	21.0	27.3	17.7	26.0	16.5
7	178.5	87.5	M	7.1	14.1	32.7	51.4	70.3	87.0	125.7	20.2	16.8	24.0	35.5	24.0	35.0	21.0
8	162.5	55.8	F	8.7	14.0	30.1	46.9	64.0	83.8	117.6	19.0	15.6	21.4	30.5	18.5	29.4	17.7
9	170.0	49.4	F	10.2	12.8	32.4	49.2	68.9	84.6	122.0	19.0	14.8	20.0	29.3	19.3	27.5	18.2
10	169.8	60.8	F	10.4	13.4	30.3	44.7	64.6	78.1	121.2	19.2	15.9	20.5	33.2	20.5	27.8	19.2
11	160.0	67.6	F	10.7	14.4	32.8	45.9	64.8	81.0	116.7	18.8	15.6	20.0	34.8	20.6	27.9	19.0
12	165.0	80.3	F	8.3	12.8	31.7	44.8	65.6	84.0	120.7	18.7	15.5	24.6	35.0	23.6	37.2	21.5
13	154.2	41.7	F	12.1	13.0	29.5	45.4	61.8	77.3	109.9	18.3	15.0	19.2	29.1	17.2	25.2	16.6
14	163.5	49.4	F	9.5	13.1	27.8	44.0	66.3	78.3	115.2	18.1	14.3	21.5	29.4	18.5	31.1	16.4
15	156.7	44.0	F	11.6	15.2	30.1	46.9	65.8	81.0	112.8	18.6	15.5	38.0	28.7	17.5	24.2	15.8
16	141.1	41.7	M	10.7	12.8	25.5	40.2	55.2	70.7	99.6	19.5	14.5	17.7	25.0	17.5	25.4	16.8
17	122.5	24.9	M	11.6	13.8	24.3	35.8	51.8	65.7	91.8	18.5	13.5	14.0	22.0	12.5	23.0	12.0

EXHIBIT 16.—Anthropometric Characteristics of Thirty Model Persons Selected to Match the Heights and Weights of the X-ray Exposure Study Population.

Person number	Height	Weight	Sex	Distance from vertex to							Skull		Thorax		Abdomen		Pub.sym. thickness
				Nasion	Ext. aud. canal	Sternal notch	Xiphoid process	Bi-iliac crest	Pubic sym.	Knee	Thick-ness	Width	Thick-ness	Width	Thick-ness	Width	
	(cm)	(kg)		(cm)							(cm)						
18	185.5	80.7	M	8.3	14.0	33.8	52.7	74.8	89.7	130.0	20.0	16.0	23.0	38.0	20.5	33.0	20.5
19	114.3	18.6	M	11.8	14.5	24.3	36.4	50.8	62.6	81.8	18.5	14.5	14.0	19.3	11.5	19.5	11.0
20	132.6	26.3	F	11.0	12.3	25.7	38.3	53.5	64.5	93.0	17.5	15.0	14.7	22.5	14.5	21.5	14.0
21	137.5	28.1	F	12.8	13.6	28.1	41.3	54.5	67.5	98.6	17.5	14.0	14.0	24.8	14.2	22.0	14.0
22	183.5	59.0	M	10.2	13.7	32.4	53.4	73.6	94.0	130.8	19.6	14.6	18.5	35.0	19.0	30.0	17.0
23	106.3	17.2	F	13.6	13.3	22.5	32.6	47.2	57.6	76.8	17.0	14.0	13.5	20.0	12.0	19.5	11.0
24	171.5	63.0	M	11.2	14.5	30.0	49.5	67.5	82.3	120.5	20.0	16.0	18.5	33.5	17.5	31.0	18.0
25	170.2	57.6	M	7.2	12.4	31.5	49.6	67.3	84.0	119.6	18.7	15.3	20.5	35.0	19.5	30.2	18.0
26	172.0	74.4	M	8.0	14.5	30.2	49.2	68.3	82.6	120.6	19.5	15.9	23.0	37.0	21.5	35.1	19.3
27	160.3	50.3	F	10.2	13.9	29.3	46.2	65.3	78.9	115.9	19.0	15.0	20.0	30.7	18.0	34.0	17.0
28	175.3	86.2	M	9.8	14.2	32.0	49.6	72.4	88.4	125.6	20.5	16.4	23.0	34.8	22.0	38.7	20.2
29	160.0	62.6	F	11.7	13.8	28.4	48.2	55.6	84.0	115.9	19.0	15.7	24.0	32.6	22.0	39.6	19.5
30	153.5	76.2	F	11.5	15.0	28.8	44.5	67.7	81.7	119.0	19.0	15.9	23.5	37.2	23.0	43.0	21.0

EXHIBIT 16.–Continued.

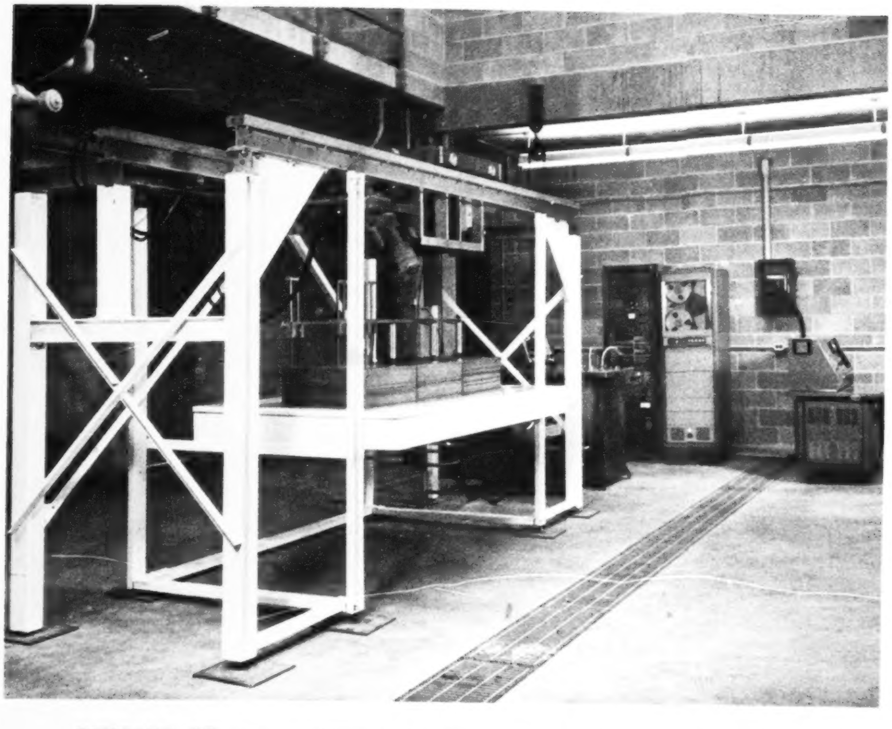


EXHIBIT 17.—Experimental Setup for Determination of Scattered-to-Direct Exposure Ratios.

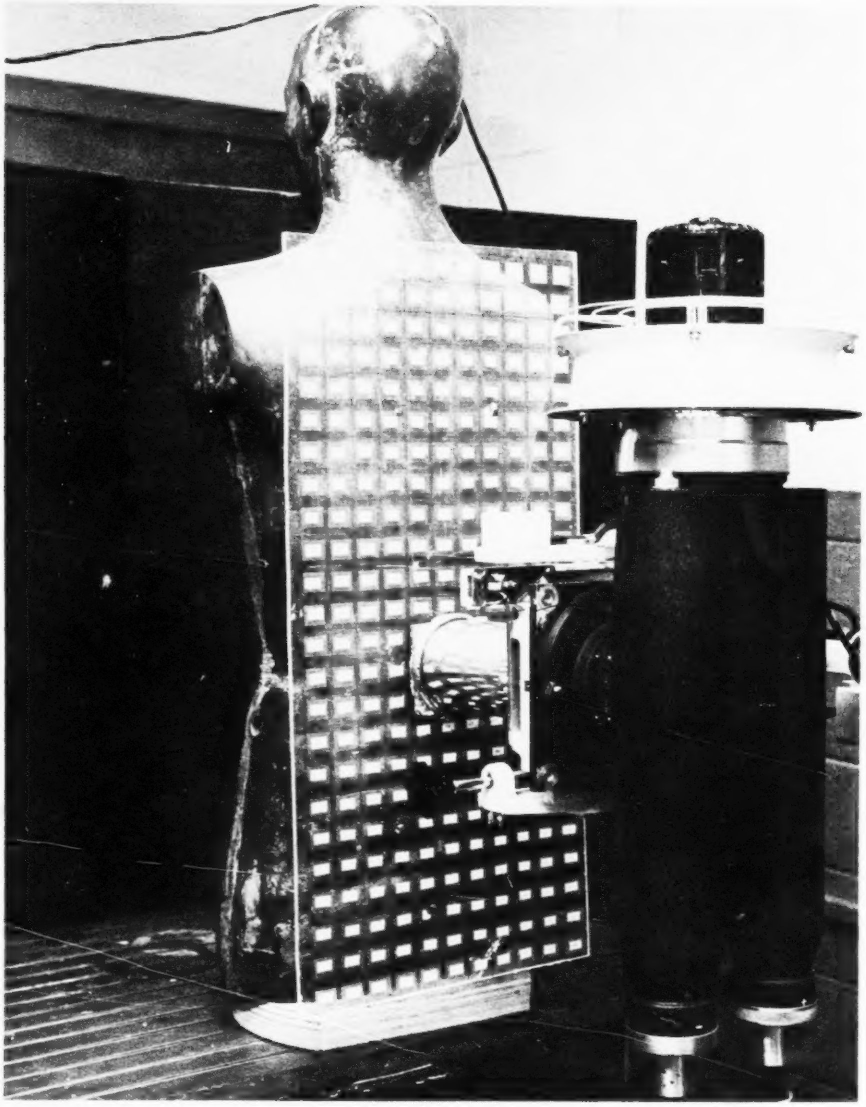


EXHIBIT 18.—The RANDO Phantom, Reference Grid System and X-ray Equipment Used to Determine the Exposure Ratios for the Postero-anterior Position.

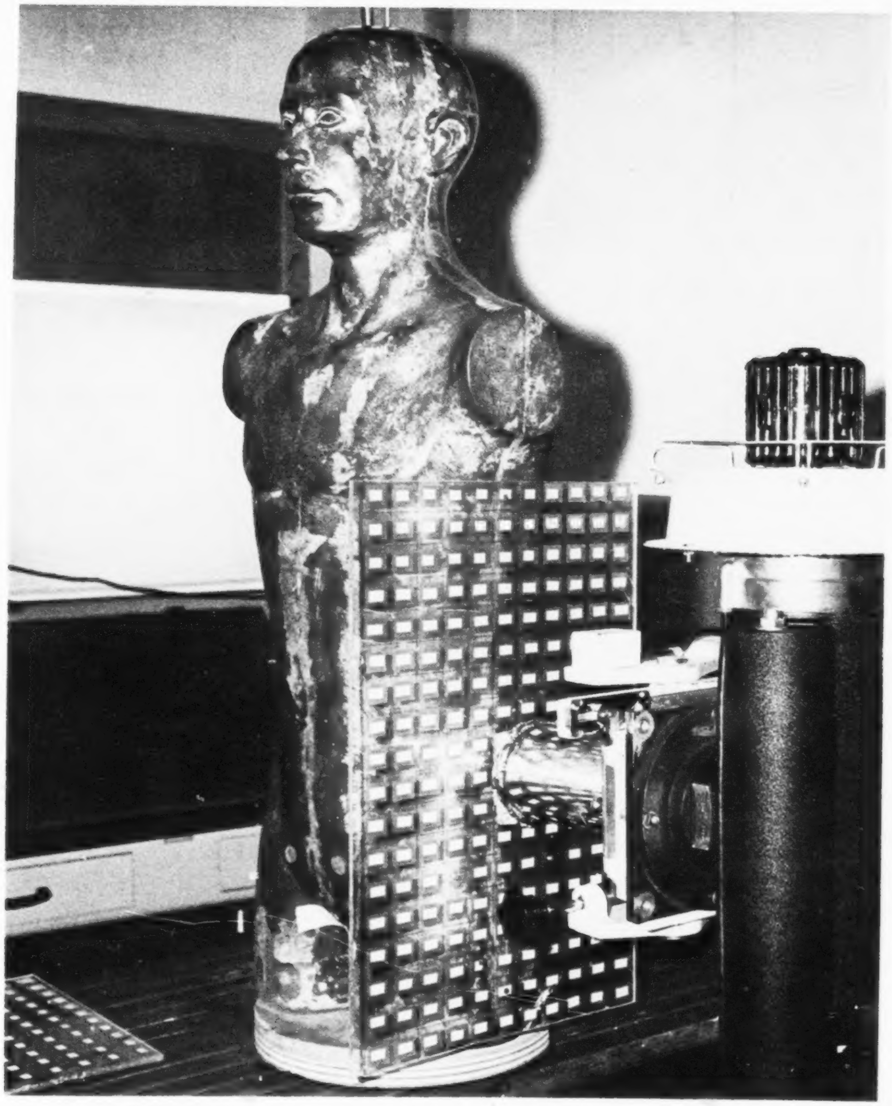


EXHIBIT 19.—The RANDO Phantom, Reference Grid System and X-ray Equipment Used to Determine the Exposure Ratios for the Left-lateral Position.

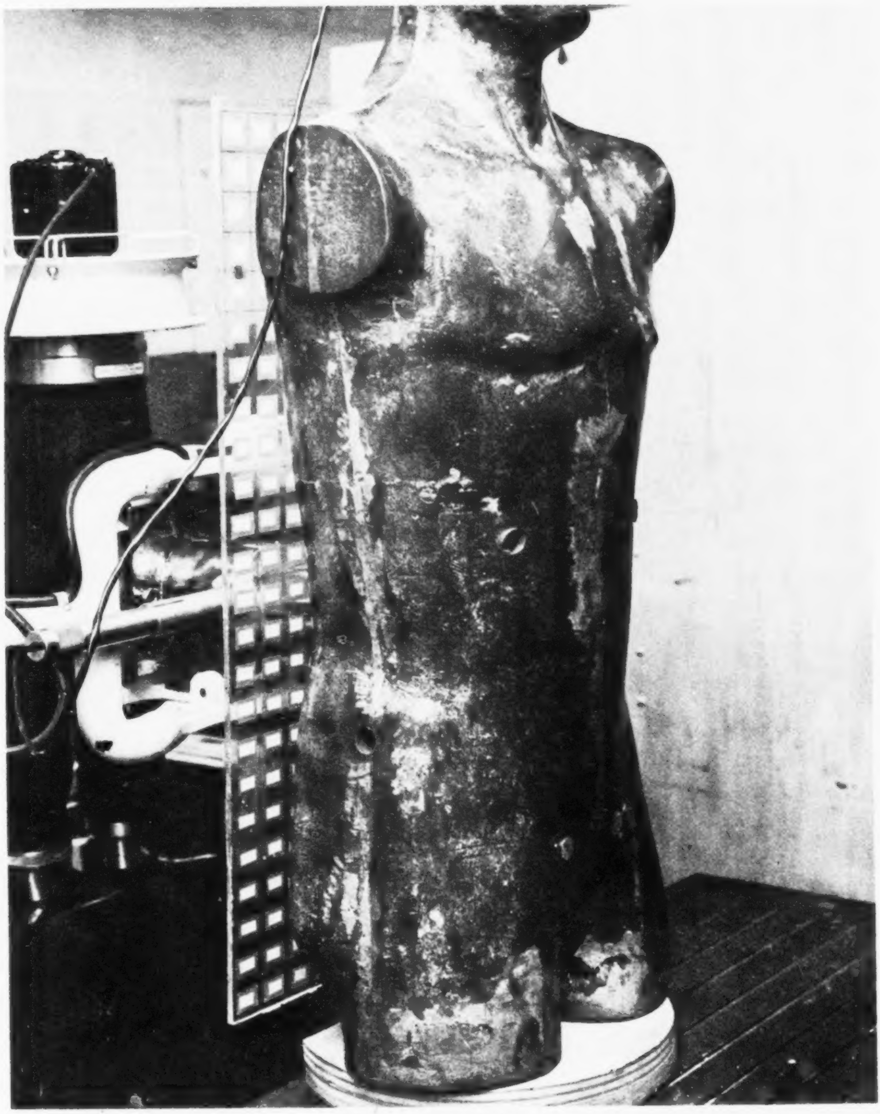


EXHIBIT 20.—The RANDO Phantom, Reference Grid System and X-ray Equipment Used to Determine the Exposure Ratios. This View Shows the Victoreen Rate-meter Probe Placed Within the Collimator for Monitoring the X-ray Beam.

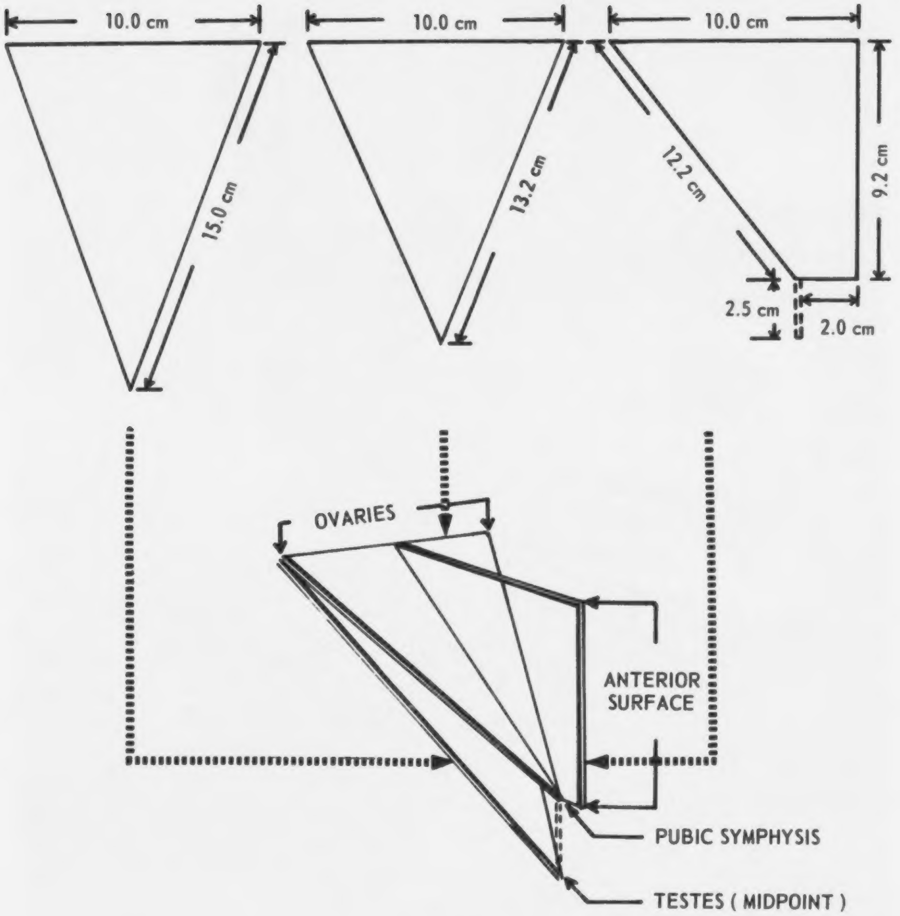

10.0 cm
15.0 cm
10.0 cm
13.2 cm
10.0 cm
12.2 cm
9.2 cm
2.5 cm
2.0 cm
OVARIES
ANTERIOR SURFACE
PUBIC SYMPHYSIS
TESTES (MIDPOINT)

EXHIBIT 21.—Model for Adult Male and Female Gonads Relative to Pubic Symphysis.

1		2		3		4		5		6		7		8		9		10		11	
12		13		14		15		16		17	.00016	18		19		20		21		22	
23		24		25		26		27		28	.00017	29		30		31		32		33	
34		35		36		37		38		39	.00021	40		41		42		43		44	
45		46		47		48		49		50	.00027	51		52		53		54		55	
56		57		58		59		60		61	.00022	62		63		64		65		66	
67		68		69		70		71		72	.00038	73	.00016	74		75		76		77	
78		79		80		81		82	.00049	83	.00028	84	.00024	85		86		87		88	
89		90		91		92		93	.00054	94	.00043	95	.00034	96		97		98		99	
100		101		102		103	.00016	104	.00038	105	.00082	106	.00040	107		108		109		110	
111		112		113		114	.00028	115	.00043	116	.00106	117	.00070	118		119	.00049	120		121	
122		123		124		125	.00069	126	.00077	127	.00128	128	.00131	129	.00013	130	.00046	131	.00016	132	.00010
133		134		135		136	.00128	137	.00087	138	.00231	139	.00183	140	.00087	141	.00081	142	.00062	143	.00036
144		145		146	.00090	147	.00166	148	.00287	149	.00378	150	.00261	151	.00128	152	.00069	153	.00072	154	.00098
155		156	.00018	157	.00128	158	.00159	159	.00520	160	.01770	161	.00415	162	.00200	163	.00129	164	.00086	165	.00054
166	.00061	167	.00023	168	.00149	169	.00192	170	.00441	171	.01790	172	.00617	173	.00240	174	.00130	175	.00089	176	.00082
177	.00076	178	.00089	179	.00164	180	.00272	181	.00453	182	.00568	183	.00482	184	.00295	185	.00090	186	.00107	187	.00087
188	.00038	189	.00034	190	.00157	191	.00249	192	.00407	193	.00388	194	.00394	195	.00263	196	.00016	197	.00038	198	.00031

EXHIBIT 22.—Typical Printout of Exposure Ratio Grid System for the Postero-anterior Position, Fluoroscopic Dose Estimation System; 4 mm Aluminum Equivalent Half-value-layer; Testes.

1	2	3 .00010	4	5 .00010	6 .00014	7 .00010	8	9	10	11
12	13 .00010	14 .00023	15 .00016	16 .00024	17 .00024	18 .00022	19	20 .00012	21	22
23	24 .00015	25 .00035	26 .00038	27 .00033	28 .00032	29 .00034	30 .00022	31 .00028	32	33
34 .00010	35 .00048	36 .00075	37 .00063	38 .00063	39 .00063	40 .00065	41 .00039	42 .00048	43 .00010	44
45 .00019	46 .00079	47 .00100	48 .00117	49 .00118	50 .00095	51 .00091	52 .00061	53 .00055	54 .00019	55
56 .00028	57 .00131	58 .00200	59 .00259	60 .00202	61 .00163	62 .00158	63 .00100	64 .00078	65 .00028	66
67 .00059	68 .00226	69 .00368	70 .00509	71 .00329	72 .00302	73 .00218	74 .00142	75 .00099	76 .00061	77
78 .00059	79 .00412	80 .00746	81 .01090	82 .01060	83 .00550	84 .00361	85 .00208	86 .00133	87 .00072	88 .00010
89 .00058	90 .00616	91 .01540	92 .02020	93 .01540	94 .00803	95 .00487	96 .00276	97 .00154	98 .00086	99 .00014
100 .00121	101 .00742	102 .02020	103 .07690	104 .02020	105 .01290	106 .00568	107 .00299	108 .00160	109 .00099	110 .00030
111 .00220	112 .00575	113 .01540	114 .02020	115 .01540	116 .00953	117 .00485	118 .00248	119 .00139	120 .00087	121 .00026
122 .00241	123 .00384	124 .00548	125 .00756	126 .00781	127 .00558	128 .00336	129 .00184	130 .00128	131 .00084	132 .00043
133 .00129	134 .00237	135 .00295	136 .00359	137 .00417	138 .00361	139 .00228	140 .00138	141 .00094	142 .00078	143 .00054
144 .00100	145 .00139	146 .00152	147 .00227	148 .00229	149 .00194	150 .00142	151 .00107	152 .00065	153 .00085	154 .00066
155 .00073	156 .00100	157 .00102	158 .00144	159 .00125	160 .00115	161 .00087	162 .00079	163 .00058	164 .00051	165 .00046
166 .00078	167 .00059	168 .00073	169 .00083	170 .00072	171 .00102	172 .00064	173 .00056	174 .00045	175 .00044	176 .00040
177 .00054	178 .00039	179 .00049	180 .00061	181 .00053	182 .00076	183 .00048	184 .00048	185 .00029	186 .00039	187 .00039
188 .00042	189 .00039	190 .00039	191 .00043	192 .00051	193 .00046	194 .00048	195 .00041	196 .00041	197 .00031	198 .00033

EXHIBIT 22.—Typical Printout of Exposure Ratio Grid System for the Postero-anterior Position, Fluoroscopic Dose Estimation System; 4 mm Aluminum Equivalent Half-value-layer; Left Ovary — continued.

1		2		3		4		5	.00010	6	.00014	7	.00010	8		9	.00010	10		11	
12		13		14	.00012	15		16	.00022	17	.00024	18	.00024	19	.00016	20	.00023	21	.00010	22	
23		24		25	.00028	26	.00022	27	.00034	28	.00032	29	.00033	30	.00038	31	.00035	32	.00015	33	
34		35	.00010	36	.00048	37	.00039	38	.00065	39	.00063	40	.00063	41	.00063	42	.00075	43	.00048	44	.00010
45		46	.00019	47	.00055	48	.00061	49	.00091	50	.00095	51	.00118	52	.00117	53	.00100	54	.00079	55	.00019
56		57	.00028	58	.00078	59	.00100	60	.00158	61	.00163	62	.00202	63	.00259	64	.00200	65	.00131	66	.00028
67		68	.00061	69	.00099	70	.00142	71	.00218	72	.00302	73	.00329	74	.00509	75	.00368	76	.00226	77	.00059
78	.00010	79	.00072	80	.00133	81	.00208	82	.00361	83	.00550	84	.01060	85	.01090	86	.00746	87	.00412	88	.00059
89	.00014	90	.00086	91	.00154	92	.00276	93	.00487	94	.00803	95	.01540	96	.02020	97	.01540	98	.00616	99	.00058
100	.00030	101	.00099	102	.00160	103	.00299	104	.00568	105	.01290	106	.02020	107	.07690	108	.02020	109	.00742	110	.00121
111	.00026	112	.00087	113	.00139	114	.00248	115	.00485	116	.00953	117	.01540	118	.02020	119	.01540	120	.00575	121	.00220
122	.00043	123	.00084	124	.00128	125	.00184	126	.00336	127	.00558	128	.00781	129	.00756	130	.00548	131	.00384	132	.00241
133	.00054	134	.00078	135	.00094	136	.00138	137	.00228	138	.00361	139	.00417	140	.00359	141	.00295	142	.00237	143	.00129
144	.00066	145	.00085	146	.00065	147	.00107	148	.00142	149	.00194	150	.00229	151	.00227	152	.00152	153	.00139	154	.00100
155	.00046	156	.00051	157	.00058	158	.00079	159	.00087	160	.00115	161	.00125	162	.00144	163	.00102	164	.00100	165	.00073
166	.00040	167	.00044	168	.00045	169	.00056	170	.00064	171	.00102	172	.00072	173	.00083	174	.00073	175	.00059	176	.00078
177	.00039	178	.00039	179	.00029	180	.00048	181	.00048	182	.00076	183	.00053	184	.00061	185	.00049	186	.00039	187	.00054
188	.00033	189	.00031	190	.00041	191	.00041	192	.00048	193	.00046	194	.00051	195	.00043	196	.00039	197	.00039	198	.00042

EXHIBIT 22.—Typical Printout of Exposure Ratio Grid System for the Postero-anterior Position, Fluoroscopic Dose Estimation System; 4 mm Aluminum Equivalent Half-value-layer; Right Ovary — continued.

Representative products and manufacturers are named for identification only and listing does not imply endorsement by the Public Health Service and the U.S. Department of Health, Education, and Welfare.

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